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Characterization of Suspended-Sediment Transport Conditions for Stable, “Reference” Streams in Selected Ecoregions of EPA Region 8

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CHARACTERIZATION OF SUSPENDED-SEDIMENT TRANSPORT CONDITIONS FOR STABLE, "REFERENCE" STREAMS IN SELECTED ECOREGIONS OF EPA REGION 8

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EXECUTIVE SUMMARY

As a result of 'natural' and human-induced changes to precipitation, runoff production and land use, water-quality issues due to excessive erosion and transport of suspended-sediment are a primary concern throughout the surface waters of EPA Region 8. This area covers a number of Level III Ecoregions that are the subject of this investigation and report: Ecoregion 15, Northern Rockies, 17, Middle Rockies, 42, Northwest Glaciated Plains, 43, Northwestern Great Plains, 46 Northern Glaciated Plains, and 48, Lake Agassiz Plain. This study aimed to determine "background" or "reference" rates of suspended-sediment transport so as to provide TMDL practitioners with a scientifically-defensible methodology by which to develop water-quality targets for sediment. The basis for establishing "reference" conditions in this study relies on sediment-transport characteristics of geomorphically stable streams within an ecoregion. As opposed to a drinking water standard that may be similar across the country, differences in topography, geology, climate and land use across the different ecoregions results in "background" different rates of sediment transport for stable streams.

Sites across the region were selected based on locations of past and present USGS stream-gauge locations where historical flow and sediment-transport data were available. Raw flow and sediment-concentration data from the gauging stations were used to calculate daily and then annual sediment loads for the period of flow record for each site. Sediment yields were obtained by dividing loadings values by drainage area so that basins of different size could be compared. Rapid Geomorphic Assessments (RGAs) conducted in the field and/or analysis of the gauge record was used to differentiate whether the stream was stable or unstable during the period of sediment sampling.

Suspended-sediment yields at an 'effective discharge' (the flow that occurs, on average, once every 1.5 years or $Q_{1.5}$) and the mean-annual yield were sorted into stable and unstable groups based on the RGAs. 'Reference' transport values were determined from the stable-streams distribution of suspended-sediment yields in a specific ecoregion as the median and inter-quartile range.. At the $Q_{1.5}$ discharge, 'reference' yields ranged over two orders of magnitude; from 0.0039 T/d/km^2 for Ecoregion 46, to 0.116 T/d/km^2 for Ecoregion 17. Mean-annual 'reference' suspended-sediment yield values varied by a single order of magnitude, from 0.351 T/y/km^2 to 4.73 T/y/km^2 also for Ecoregions 46 and 17, respectively. Statistical analysis of the differences between stable and unstable sites within each Level III Ecoregion were significant at the 0.05 probability level and provide support for: (1) the overall approach of determining 'reference' or 'target' sediment-transport rates based on a geomorphically-defined 'reference' condition and (2) differentiating 'reference' sediment-transport rates by ecoregion for us in developing water-quality targets for sediment in EPA Region 8..

Using the same approach and where sufficient data were available, bed-material (or habitat) conditions were also evaluated within each Level III Ecoregion. Embeddedness was calculated as the percentage of fine material (finer than 2mm) present in a coarse-dominated bed material. 'Reference' values of embeddedness were found to be within the range previously published values (2 and 11 %). Suspended-sediment yield data were

also sorted by drainage-area size classes and individual watershed in some cases to further investigate further refinement of the 'reference' values.

To provide sediment-transport data in a form that would be potentially more useful to biologists and aquatic ecologists seeking functional links between sediment transport and biologic metrics, all sediment-transport data were re-characterized in terms of the frequency and duration of suspended-sediment concentrations. In addition, sediment 'dosage' was calculated as the product of concentration and duration and was also differentiated by stability class. As expected, median suspended-sediment concentrations were lower in stable or 'reference' channels at a given percent exceedance (or frequency) than in unstable channels, with differences more dramatic at moderate and high flows. The durations of specific concentrations are almost always greater for the unstable channels in all of the ecoregions, lending further support to the idea of using these types of data to investigate differences in biologic distribution and function. Sediment-dosage data for all of the Ecoregions also show distinct differences between stable and unstable sites across the range of concentrations. The same can be said for the inter-quartile ranges of these data, providing further support of their potential value. The greatest sediment-dosage impacts occur in Ecoregions 42 and 43 across the entire range of concentration exceedances. This suggests that impairment of biologic communities due to sediment dosage may occur not only at the high flow-concentration events, but may also be linked to the generally higher concentrations that persist over long periods of time at moderate flows. This appears to be the case with all of the 'Plains' Ecoregions.

Frequency and duration of suspended-sediment concentrations, and dosage were used in the ecological analysis which attempted to relate sediment metrics to biological impairment. The ecological analysis consisted of a functional-traits approach using fish data from the Northwestern Great Plains (Ecoregion 43) because this ecoregion had greatest number of sediment-collection sites as well as the greatest potential of finding sites with co-located fish data (58 sites). Sediment metrics were computed for fish exposure months (March through November), the period of time fish would be expressing their biological traits of habitat rearing preferences, feeding habits, and spawning behavior. For each site, occurrences of 20 different functional traits were compiled based on the presence of fish species that express that particular trait. A correlation analysis among suspended-sediment metrics and fish functional traits found three different types of impairment response; correlations across a broad range of concentration frequencies, and at both upper and lower ranges of concentration frequencies. Trait occurrences for fish that prefer pool habitat in streams were correlated across a broad range of frequency and duration of concentrations. In contrast, trait occurrences for fish that prefer shallow water habitat were correlated at the upper range of frequency and duration of concentrations; and piscivores were correlated with the lower range of frequency and duration of concentrations.

Overall, the functional traits approach appeared useful to identify potential suspended-sediment "thresholds" for biological impairment. Traits related to rearing habitat, feeding trophic structure, and spawning behavior were found to be impacted by elevated levels of suspended sediment. Of the twenty functional traits used in this study, ten correlated with

a different suspended-sediment concentration frequency, duration and/or dosage. This result illustrates the complexity and futility in identifying a single biologically-based "threshold"; because different concentration levels appear to impact fish functional traits differentially. A functional traits approach produces multiple sediment thresholds for impairment. Regional biologists with knowledge of fish distributions and traits of species to be protected can, therefore, use a specific threshold based on which ecological function(s) are to be protected. The ecological analysis found the sediment-dosage metric useful. Of the ten functional traits only one did not correlate with dosage metrics but rather with the sediment-duration metric only.

Using ordination eigenanalysis, channel stability was found to be at least as important two natural environmental gradients, drainage area and elevation in explaining variance of functional trait occurrences among sites. This finding suggests channel stability, expressed in terms of elevated sediment concentrations, is an important environmental condition that affects fish distribution, but is co-dependent on watershed size and elevation.

Sufficient evidence was found in the ecological analysis to support the utility of RGA determinations of stable-unstable reaches, and subsequent sediment-transport differences. Whether the ecological consequences are direct or indirect, it appears fish species that build and guard nests occupied stable reaches more than unstable reaches. Likewise, fish species that spawn by egg dispersion were found more in unstable reaches than stables reaches. This finding suggests that sedimentation imposes an ecological stress on fish species that build nests for spawning. In general, ordinations with autecological attributes explained more than 50% of the variance for Axis 1 and 2, which is reasonable considering the number of environmental factors that affect fish distribution. Findings suggest that fish community structure is altered because watershed disturbances, observed by differences in stable and unstable reaches. Sedimentation may be directly impacting spawning success of nest builders, and indirectly modifying physical habitat to promote herbivores and piscivores. However, many fish species found in this ecoregion were tolerant species, found in both stable and unstable reaches.

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1. INTRODUCTION AND PROBLEM

Excessive erosion and transport of sediment in the nation's surface waters has resulted in sediment being listed as one of the principal pollutants of surface waters in the United States by the 1996, 1998 and 2002 National Water Quality Inventory (Section 305 (b) Report to Congress). Water-quality impairment by sediment can be separated into two groups: sediment quality, where impairment is due to chemical constituents adsorbed onto the surface of fine-grained sediments, and sediment quantity where impairment is due to the amount of sediment in transport and/or alteration of substrate materials (bed material) by erosion or deposition.

Environmental Protection Agency (EPA) water quality information from across the nation found 'siltation' to be the leading cause of water quality impairment in 1996, 1998 and 2002. In 2000 'siltation' ranked a close second to bacteria and pathogens. This information has been compiled from the various Water Quality Reports available online in Tables 1 and 2. However, EPA does state that such data should not be used to compare water quality conditions between states or identify national trends due to differences in state assessment methods and changes in EPA guidance. Comparison of data between states should be made with caution, as the various states participating in data collection are not required to use a unified methodology.

For the purpose of developing water-quality target values for sediment, sediment-transport rates and amounts can be viewed as (1) "natural," "reference" or background, resulting from generally stable channel systems, (2) "impacted", with greater transport rates and amounts, reflecting a disturbance of some magnitude and more pervasive erosion, and (3) "impaired", where erosion and sediment-transport rates and amounts are so great that biologic communities and other designated stream uses are adversely affected. Impairment of designated stream uses by clean sediment (neglecting adsorbed constituents) may occur along the channel bed such as deposition of fines amidst a coarser-grained substrate, or by elevated concentrations of suspended-sediment in the water column. Fully mobile streambeds and deposition of fines amidst interstitial streambed gravels, can pose hazards to fish and benthic macro-invertebrate communities by disrupting habitats, degrading spawning habitat, and reducing the flow of oxygen through gravel beds. Although lethal or sub-lethal thresholds are currently unknown for many species, high concentrations of suspended-sediment over certain durations have been shown to adversely affect aquatic organisms (Newcombe and MacDonald, 1991 and Newcombe and Jensen, 1996). It is therefore important to determine the quantity and quality of sediment within a river system that does not adversely impact the specified designated uses.

One way of accomplishing this is by differentiating between rates and conditions of sediment transport for stable and unstable streams within a given area or region. Unimpaired or stable, 'reference' streams are defined in geomorphic terms for the purpose of this study. A stable stream is one in dynamic equilibrium, capable of transporting all sediment delivered to the system from upstream without altering its dimensions over a period of years. Conversely, an unstable stream is one in which the supply of sediment from upstream is not in balance with the ability of the stream to transport that sediment through the reach without alterations to its geometry over a period of years. The definition of a 'stable channel' used here is consistent with the definition

used for the past 60 years since Mackin published his work on the Graded River in the 1940's (Mackin, 1948). Most alluvial rivers have active floodplains (if they are not deeply incised) where there is a transfer of sediment from upstream. The definition brings into consideration rates and scales of channel change. Stable alluvial rivers are not static, but may alter their geometry at very low rates, or may scour and fill over the course of a storm event. We have extended Mackin's (1948) definition which referred to only the slope of the channel to include lateral change.

Using this general concept, 'reference' suspended-sediment transport rates have been developed for various Level III Ecoregions of the United States (Simon *et al.*, 2004a) and for all of the ecoregions in EPA Region 4 (southeastern United States) by Klimetz and Simon (2006) and Simon and Klimetz, (2008a, 2008b). The continental United States is divided into 84 Level III Ecoregions, which have similar characteristics, including among others, climatic and physiographic conditions, geology and ecology (Omernik, 1995). The ecoregions in EPA Region 8 selected for this study were the Northern Rockies, Ecoregion 15; Middle Rockies, Ecoregion 17; Northwest Glaciated Plains, Ecoregion 42; Northwestern Great Plains, Ecoregion 43; Northern Glaciated Plains, Ecoregion 46; and Lake Agassiz Plain, Ecoregion 48. These ecoregions lie mainly in Montana, North Dakota, South Dakota and Wyoming, but also includes parts of Idaho, Washington, Nebraska and Minnesota.

This study aimed to determine suspended-sediment transport rates for 'reference' (stable) streams, specific to select ecoregions within EPA Region 8, with the intention that the methodology and findings will be used by States and Tribes, as well as the EPA to develop sediment TMDLs in EPA Region 8 (Figure 1).

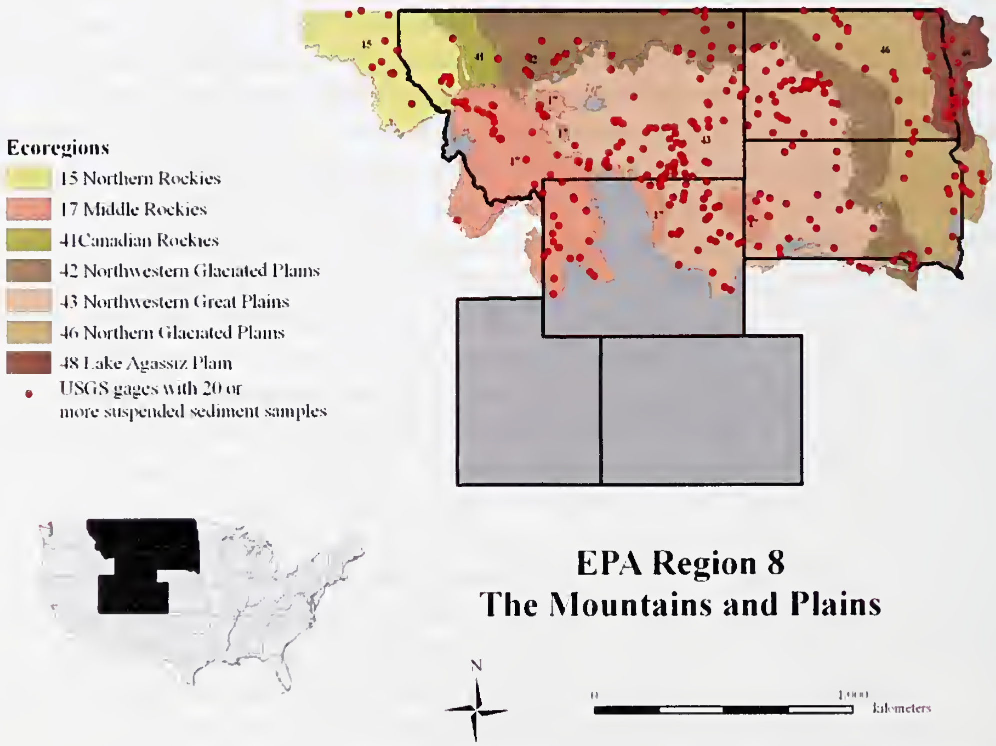

Figure 1 – EPA Region 8 encompasses six states across the West and Midwestern United States.

Table 1 – Compilation of data from the National Water Quality Inventory Report to Congress (305(b) Report) for the states relevant to the selected Ecoregions of EPA Region 8.

State	Total miles of river and streams	Year of report	Total river miles assessed for water quality		Overall Water Quality Attainment for Rivers and Streams (river miles)					
					Good		Threatened		Impaired	
Idaho	115595	2002	50584.25	43.76%	19094.24	37.75%	0	0.00%	31490.01	62.25%
		2000	17333	15.00%	8434	48.66%	669	3.86%	8229.6	47.48%
Minnesota	91944	2004	9878.79	10.74%	19094.24	37.75%	0	0.00%	31490.01	62.25%
		2002	5048.91	5.88%	2402.8	44.42%	527.06	9.74%	2479.05	45.83%
		2000	11403	12.00%	1149.6	10.24%	2181.7	19.43%	7899.6	70.33%
		1996	7793			10.00%		39.00%		51.00%
Montana	176750	2004	13195.39	7.47%	3370.4	25.54%	8.1	0.06%	9816.89	74.40%
		2002	12727.09	7.20%	3038.5	23.87%	8.1	0.06%	9680.49	76.06%
		2000	11443	6.00%	2858.2	24.98%	8.1	0.07%	8576.4	74.95%
		1996	17894			19.00%		2.00%		79.00%
Nebraska	81573	2004	7155.83	8.77%	3872.05	54.11%	0	0.00%	3283.78	45.89%
		2002	7580.67	9.29%	3136.13	41.37%	101.4	1.34%	4343.14	57.29%
		2000	6500	8.00%	2741	42.17%	0	0.00%	3759	57.83%
		1996	81573			25.00%		9.00%		67.00%
North Dakota	54427	2004	9176.83	16.86%	2990.99	32.59%	3835.47	41.80%	2350.37	25.61%
		2002	7708.88	14.16%	2302.32	29.87%	3298.87	42.77%	2109.69	27.37%
		2000	14965	27.00%	1656.9	11.07%	6083.5	40.65%	7224.2	48.28%
		1996	53989			9.00%		62.00%		29.00%
South Dakota	9937	2004	7375.63	74.22%	4233.33	57.40%	10.6	0.14%	3131.7	42.46%
		2002	4265.2	42.92%	1823.6	42.76%	0	0.00%	2441.6	57.24%
		2000	3564	36.00%	1786	50.11%	0	0.00%	1778	49.89%
		1996	9937			17.00%		0.00%		83.00%
Wyoming	108767	2004	5903.05	5.43%	4654.43	78.85%	387.89	6.57%	860.73	14.58%
		2002	3969.99	3.65%	2479.79	62.46%	491.84	12.39%	998.36	25.15%
		2000	2955	3.00%	2124.1	71.89%	379.2	12.83%	451.5	15.28%
		1996	113422			37.00%		4.00%		59.00%
Nationwide	3692830	2002	695540.37	18.83%	358034.88	51.48%	27749.97	3.99%	309755.53	44.53%

State	Total miles of river and streams	Year of report	Total river miles assessed for water quality		Overall Water Quality Attainment for Rivers and Streams (river miles) Good		Threatened		Impaired	
		2000	699946	19.00%	367129	53.00%	59504	8.00%	269258	39.00%
		1998	842426	23.00%	463441	55.00%	85544	10.00%	291264	35.00%
		1996	693905	19.00%		56.00%		8.00%		36.00%

Compiled from:

USEPA, 2008. National Assessment Database available online at: http://www.epa.gov/waters/305b/index.html

USEPA, 2002. Water Quality Report to Congress

USEPA, 2000a. Water Quality Report to Congress

USEPA, 1998. Water Quality Report to Congress

USEPA, 1996a. Water Quality Report to Congress

Table 2 – Major causes of pollution in rivers and streams across the United States, in order of severity.

	Cause of Pollution 2002	2000	1998	1996
1	**Sedimentation/siltation**	Pathogens	**Sedimentation/siltation**	**Sedimentation/siltation**
2	Pathogens	**Sedimentation/siltation**	Pathogens	Nutrients
3	Habitat alterations	Habitat alterations	Nutrients	Bacteria
4	Metals	Oxygen-depleting substances	Oxygen-depleting substances	Oxygen-depleting substances
5	Nutrients	Nutrients	Metals	Pesticides
6	Thermal modifications	Thermal modifications	Pesticides	Habitat alterations
7	Organic enrichment/low Dissolved Oxygen	Metals	Habitat alterations	Suspended solids
8	Flow alterations	Flow alterations	Thermal modifications	Metals
9	Cause unknown			
10	pH/acidity/caustic conditions			

2. OBJECTIVES

The main purpose of this study was to use scientifically-defensible methodologies by which to determine 'reference' suspended-sediment transport rates for selected Level III Ecoregions located in EPA Region 8. Where there were sufficient data available, 'reference' rates were also to be determined over smaller geographic areas (Level IV Ecoregions). Suspended-sediment transport yields, expressed as mass per unit drainage area (T/d/km^2) were to be initially calculated at a constant flow-recurrence interval representing the channel-forming or effective discharge ($Q_{1.5}$; Simon *et al.*, 2004a), derived from the annual maximum discharge series. Results provided in this format to other States and EPA regions indicated that a transport rate representing annual values would be easier for stakeholders to grasp. As transport rates at the effective discharge ($Q_{1.5}$) cannot be multiplied by 365 to obtain an annual suspended-sediment transport value, an additional goal was to determine 'reference' annual transport rates using mean-daily discharge data for all sites.

As suspended-sediment transport rates expressed as yields (as in T/y/km^2) cannot be functionally related to the life cycle of aquatic biota, a secondary objective of this study was to create additional sediment-transport metrics that could ultimately be used by biologists and aquatic ecologists to develop functional links between sediment and biota. In addition, these associations aid in directing appropriate TMDL management actions that target a specific environmental condition causing ecological degradation. This was carried out by evaluating whether a functional traits approach using fish could effectively relate biotic response and suspended-sediment exposure measures, in order to identify possible candidate causes for biological impairment. USEPA (2000b) defines 'candidate cause' as a stressor that occurs at a magnitude, duration and frequency of exposure. Essentially it is the contact of a stressor with the biological resource that results in a change in ecological condition. In this study, change in ecological condition equates to change in functional trait composition due to excessive suspended sediment. We hypothesize that each functional trait has a characteristic response along an environmental gradient of suspended sediment exposure. The functional traits analysis attempts to correlate traits with sediment exposure measures, where negatively correlated traits are those that are impacted by siltation. As channel instabilities in a watershed can lead to greater annual sediment loads, the study also investigates whether functional traits differ between sites geomorphologically classified as stable versus unstable.

The geographic scope of this project is the West and Midwest United States, part of EPA Region 8, the Mountains and Plains. This study covers the states of Montana, North Dakota, South Dakota and Wyoming. Six of the Level III Ecoregions located within EPA Region 8 will be addressed in this report: Ecoregion 15, The Northern Rockies; Ecoregion 17, Middle Rockies; Ecoregion 42, Northwest Glaciated Plains; Ecoregion 43, Northwest Great Plains; Ecoregion 46, Northern Glaciated Plains; and Ecoregion 48 Lake Agassiz Plain (Table 3). The functional traits approach relating biotic response and suspended-sediment exposure was conducted in Ecoregion 43, where both biotic and suspended-sediment transport data were available.

Table 3 – Primary distinguishing characteristics of select Level III Ecoregions of EPA Region 8, The Mountains and Plains.

	Ecoregion	States	Number of gages[1]	Primary distinguishing characteristics[2]
15	**Northern Rockies**	**Idaho, Montana, Washington**	15	The high, rugged Northern Rockies is mountainous and lies east of the Cascades. Despite its inland position, climate and vegetation are, typically, marine-influenced. Douglas fir, subalpine fir, Englemann spruce, and ponderosa pine and Pacific indicators such as western red cedar, western hemlock, and grand fir are found in the ecoregion. The vegetation mosaic is different from that of the Middle Rockies which is not dominated by maritime species. The Northern Rockies ecoregion is not as high nor as snow- and ice-covered as the Canadian Rockies although alpine characteristics occur at highest elevations and include numerous glacial lakes. Granitics and associated management problems are less extensive than in the Idaho Batholith.
17	**Middle Rockies**	**Idaho, Montana, South Dakota, Wyoming**	47	The climate of the Middle Rockies lacks the strong maritime influence of the Northern Rockies. Mountains have Douglas-fir, subalpine fir, and Engelmann spruce forests and alpine areas; Pacific tree species are never dominant. Forests can be open. Foothills are partly wooded or shrub- and grass-covered. Intermontane valleys are grass- and/or shrub-covered and contain a mosaic of terrestrial and aquatic fauna that is distinct from the nearby mountains. Many mountain-fed, perennial streams occur and differentiate the intermontane valleys from the Northwestern Great Plains. Granitics and associated management problems are less extensive than in the Idaho Batholith. Recreation, logging, mining, and summer livestock grazing are common land uses.
41	**Canadian Rockies**	**Montana**	0	As its name indicates, most of this region is located in Canada. It straddles the border between Alberta and British Columbia in Canada and extends southeastward into northwestern Montana. The region is generally higher and more ice-covered than the Northern Rockies. Vegetation is mostly Douglas fir, spruce, and lodgepole pine at lower elevations and alpine fir at middle elevations. The higher elevations are treeless alpine. A large part of the region is in national parks where tourism is the major land use. Forestry and mining occur on the nonpark lands.
42	**Northwestern Glaciated Plains**	**Montana, Nebraska, North Dakota, South Dakota, Wyoming**	40	The Northwestern Glaciated Plains ecoregion is a transitional region between the generally more level, moister, more agricultural Northern Glaciated Plains to the east and the generally more irregular, dryer, Northwestern Great Plains to the west and southwest. The western and southwestern boundary roughly coincides with the limits of continental glaciation. Pocking this ecoregion is a moderately high concentration of semi-permanent and seasonal wetlands, locally referred to a Prairie Potholes.

	Ecoregion	States	Number of gages[1]	Primary distinguishing characteristics[2]
43	**Northwestern Great Plains**	**Montana, Nebraska, North Dakota, South Dakota, Wyoming**	194	The Northwestern Great Plains ecoregion encompasses the Missouri Plateau section of the Great Plains. It is a semiarid rolling plain of shale and sandstone punctuated by occasional buttes. Native grasslands, largely replaced on level ground by spring wheat and alfalfa, persist in rangeland areas on broken topography. Agriculture is restricted by the erratic precipitation and limited opportunities for irrigation.
46	**Northern Glaciated Plains**	**Minnesota, North Dakota, South Dakota**	38	The Northern Glaciated Plains ecoregion is characterized by a flat to gently rolling landscape composed of glacial till. The subhumid conditions foster a transitional grassland containing tallgrass and shortgrass prairie. High concentrations of temporary and seasonal wetlands create favorable conditions for waterfowl nesting and migration. Though the till soils are very fertile, agricultural success is subject to annual climatic fluctuations
48	**Lake Agassiz Plain**	**Minnesota, North Dakota**	13 [3]	Glacial Lake Agassiz was the last in a series of proglacial lakes to fill the Red River valley in the three million years since the beginning of the Pleistocene. Thick beds of lake sediments on top of glacial till create the extremely flat floor of the Lake Agassiz Plain. The historic tallgrass prairie has been replaced by intensive row crop agriculture. The preferred crops in the northern half of the region are potatoes, beans, sugar beets and wheat; soybeans, sugar beets, and corn predominate in the south.

[1] Number of USGS gage with 15 or more suspended-sediment samples and associated discharge.

[2] Source: USEPA (2002a) available online at: http://www.epa.gov/wed/pages/ecoregions/level_iii.htm

[3] Due to an insufficient number of gages with at least 15 suspended-sediment samples and associated instantaneous discharge, four sites were added for which discharge was calculated from mean daily discharge values

3. BACKGROUND AND DATA AVAILABILITY

EPA compiled water-quality data from approximately one million river kilometers of channels (about 19 % of the nation's waterways) that had been assessed by States, Territories and Tribes across the Nation in 2002. More than 160,000 river kilometers were significantly impaired as a result of 'sedimentation/siltation' (2002 National Water Quality Inventory Report to Congress (305(b)). Sediment was, therefore, found to be the number one factor contributing to pollution of the nation's surface waters in 2002. Those same States, Territories and Tribes are then required to determine the maximum allowable loadings to, or in a stream that does not impair the "designated use" of that particular water-body. This measure has been termed a "TMDL" (total maximum daily load). From a technical point of view, however, this should not mean that a TMDL for sediment transport needs to be expressed in terms of a total load, or a daily-maximum load. In fact neither of these metrics may be appropriate for sediment. Other metrics used to describe 'reference', impacted and impaired sediment-transport conditions such as suspended-sediment yields and concentration frequency-duration are probably more meaningful.

Initial considerations regarding the flow discharge to be used to calculate sediment loads or yields focused on a geomorphically effective flow. Historically, the bankfull discharge has been used because it has been assumed to represent a 'channel-forming discharge' (Leopold and Maddock, 1953). In fact, renewed interests in rehabilitation and restoration of stream channels has resulted in renewed popularity of using this flow for channel design (Rosgen, 1996). Because the bankfull flow has been ascribed by some over the years as having geomorphic significance as the "channel-forming flow" representing long-term sediment-transport conditions it deserves further attention here as a potential metric for sediment-transport conditions. However, in lieu of form-based estimates of the bankfull level, a flow of a given frequency and recurrence interval is perhaps more appropriate to integrate suspended-sediment transport rates for the purpose of defining long-term transport conditions at sites from diverse regions.

3.1 Bankfull Discharge, Effective Discharge and the $Q_{1.5}$

The bankfull discharge has been ascribed various meanings and levels of importance over the past 50 years since Leopold and Maddock (1953) published their research on hydraulic geometry. This work established an empirical framework for observed differences in the size and shape of alluvial channels as a function of bankfull discharge. Based on the annual-maximum flow series, the recurrence interval of the bankfull discharge often approximates the 1.5-year flow event (Dury et al., 1963; Leopold et al., 1964; Hickin, 1968; Dunne and Leopold, 1978; Williams, 1978; Harman et al., 1999; Odem et al., 1999; Castro and Jackson, 2001) although substantial variations around this average value have been noted (Williams, 1978).

Sediment water-quality issues have been linked to conditions at bankfull discharge as a potential means of identifying impacted stream systems based on "departure" from "background" or "reference" sediment-transport conditions (Simon et al., 2001). The

bankfull discharge is the maximum discharge that can be contained within the channel without overtopping the banks (Leopold et al., 1964) and generally accepted to represent the flow that occurs, on average, every 1.5 years ($Q_{1.5}$). Dunne and Leopold (1978) described the discharge at the bankfull stage as the most effective at forming and maintaining average channel dimensions. This has led to the term "bankfull discharge" being often used interchangeably with the terms "effective discharge," "channel-forming discharge," and "dominant discharge." The simple definition of "bankfull" by Leopold et al. (1964), as the "flow that just spills out onto the floodplain" has been used and abused over the years (Williams, 1978). One of the primary reasons for this confusion is that as originally defined bankfull discharge and the dimensions represented by hydraulic geometry relations refer to stable channels. A bankfull level in unstable streams can be exceedingly difficult to identify particularly in erosional channels because of a lack of depositional features and because channel dimensions, including water-surface elevations (of specific discharges), are changing with time. In searching for a meaningful discharge or range of discharges to compare sediment-transport rates and by alleviating the need for the form-based "bankfull" criteria is to use a consistent flow-frequency value that can be linked to geomorphic processes, alluvial channel form, and hence, sediment-transport rates.

The *effective discharge* is the discharge or range of discharges that transports the largest proportion of the annual suspended-sediment load over the long term (Wolman and Miller, 1960). In subsequent years various authors (Andrews, 1980; Andrews and Nankervis 1995; Whiting et al, 1999; Emmett and Wolman, 2001; and others) have altered the original definition of effective discharge from suspended-sediment load to include bed load, bed-material load, or total load to accommodate their particular sampling or analytic program. This is justified on the basis that "bed-load…is the most relevant from the standpoint of channel form adjustment…" (Knighton, 1998, p. 164). This, however, is a surprising assertion, as in most cases the suspended load represents the bulk of the annual sediment load. These authors have found that the effective discharge for bed load may be represented by the $Q_{1.5}$ (discharge with a recurrence interval of, on average, 1.5 years). In stable, non-incised stream systems, the $Q_{1.5}$ may be represented by the bankfull stage (Dunne and Leopold, 1978). For the purposes of this report we will use the definition of effective discharge as originally defined by Wolman and Miller (1960) to represent suspended-sediment transport.

The ratio between effective and bankfull discharges does, however, tend to diverge from unity with the magnitude of large, infrequent events (Wolman and Miller, 1960; Pickup and Warner, 1976; Nolan et al., 1987; Whiting, et al., 1999). Pickup and Warner (1976) found the return period of the effective discharge to range between 1.15 and 1.4 years (from the annual maximum series) using bed load transport equations to estimate sediment transport. With data from 55 streams, Nash (1994) questioned the validity of the effective discharge occurring on about 1-year intervals based on concerns of transport variability and the difficulty of describing the relation between suspended-sediment concentration and water discharge with a power function. However using a vast dataset of approximately 500 sites within the United States, Simon *et al.* (2004a) calculated the recurrence interval of the effective discharge for suspended-sediment transport. The median recurrence interval ranged from 1.1 to 1.7 years, across 17 different ecoregions

with varying hydrologic and topographic conditions. The conclusions of this report were that "the $Q_{1.5}$ proved to be a reasonably good measure of the effective discharge for suspended-sediment", and can therefore be used across a range of spatial scales in diverse environments to compare suspended-sediment transport rates.

3.2 Availability of Suspended-Sediment Data

Analysis of suspended-sediment transport at the national scale requires a large database of suspended-sediment concentrations with associated instantaneous water discharge. Data of this type permit analysis of sediment-transport characteristics and the development of rating relations (Porterfield, 1972; Glysson, 1987). Collection of suspended-sediment data is time consuming and expensive in that it must take place over a broad range of flows to accurately evaluate the long-term, sediment-transport regime at a site. However, the U.S. Geological Survey (USGS) has identified more than 6000 sites nationwide where at least 1 matching sample of suspended sediment and instantaneous flow discharge have been collected (Turcios and Gray, 2001). Almost 350 USGS gages have at least 15 suspended-sediment samples with associated instantaneous discharge data (Table 3, above), ranging from 13 in Ecoregion 48, Lake Agassiz Plain, to Ecoreigon 43, the Northern Great Plains, with 194 sites with sufficient data to create a transport rating relation. At many of these sites, data on the particle-size distribution of suspended- and bed-material sediment are also available. USGS and ARS suspended-sediment sampling strategies are usually designed to obtain samples over a broad range of flows, particularly during storms when a large proportion of the annual load may be transported. In addition, peak-flow files maintained by the USGS were available for most of the sites. This massive historical database serves as the foundation for analyzing sediment-transport characteristics over the entire range of physiographic conditions that exist in the United States, including Hawaii and Puerto Rico.

It should be stressed that the sediment-transport rates reported here represent suspended sediment that move in two different phases; wash load (generally silts and clays) and suspended bed-material load (generally sands) but exclude bed load. Because of the difficulties and expense in measuring bed-load transport, there is a general lack of comprehensive data sets on bed load transport in this and most other regions. Therefore, bed load transport rates are not included in reported values of sediment transport. In lieu of bed load transport rates, the study relies on particle-size distributions of the bed material to characterize conditions for aquatic biota on the bed, much like the suspended-sediment data is used to characterize conditions for aquatic biota in the water column. It is possible, however, to create bed-load transport relations using bed-material particle-size data, measurements of channel slope and flow information by applying any number of bed load transport equations from the literature. This was beyond the scope of this study.

To be useful for TMDL practitioners, sediment-transport relations must be placed within a conceptual and analytic framework such that they can be used to address sediment-related problems at sites where no such data exists. To accomplish this, sediment-transport characteristics and relations need to be regionalized according to attributes of

channels and drainage basins that are directly related to sediment production and transport. In a general way, attributes such as physiography, climate, geology, and ecology are differentiated within the ecoregion concept (Omernik, 1995). Ecoregions are convenient units with which to regionalize investigations concerning dominant channel processes, differentiated as stage of channel evolution (Simon and Hupp, 1986; Simon, 1989a). These Ecoregion divisions have been used successfully as a means of regionalizing hydraulic-geometry relations in the Pacific Northwest (Castro and Jackson, 2001) and for developing 'reference sediment-transport conditions in a range of ecoregions across the United States (Simon *et a.l.* 2004a, Klimetz and Simon, 2007; Simon and Klimetz, 2008).

3.3 A Functional Traits Approach for Sediment TMDLs

Excessive suspended sediment in rivers and streams beyond some natural condition, referred to as siltation, is a major cause of water quality impairment in the United States (USEPA 2003, 2006). Siltation-impaired waters are identified through state biomonitoring programs, where site biotic integrity scores do not meet set biocriteria limits for the 'aquatic life' designated use (USEPA 1996b; Barbour *et al.* 1999; Stoddard *et al.* 2006). These impaired river and stream segments are listed in accordance with §303(d) of the Clean Water Act, and total maximum daily loads (TMDLs) for sediment must be generated to meet state water quality criteria (USEPA 1999). Although 32 states have developed numeric criteria for turbidity, suspended solids, or both according to the USEPA (2006), criteria is typically written as a percent exceedance above background, however background values are not clearly defined. Defining a background level is problematic considering suspended solids and related turbidity levels change with flow stage and season, and limited scientific data exists on relationships between sediment exposure and biotic response. As stated in the USEPA (2006) framework for developing water quality criteria for sediment, a critical need exists to find useful analyses that: 1) characterizes variability of suspended sediment loads and differentiates loads between geomorphologically stable and unstable watersheds, and 2) links excessive suspended sediment loads with impairment, identifying any loss in ecological functions as loads increase.

In order to meet this need, a linkage analysis must find sediment exposure measures that correlate to biotic response measures (USEPA 1999, 2006). Sediment exposure measures have included suspended-sediment concentration (SSC), sediment yields over a designated time period (SSY, loads divided by drainage area), and surrogate measures utilizing channel stability indices (Nietch *et al.* 2005; Kaufmann *et al.* 2008). However, variability of transported suspended sediment must also be quantified and interrelated to ecosystem resilience. Accounting for this variability within different ecoregions, Simon *et al.* (2004) computed SSC (mg/L) occurrence frequencies and mean annual SSY using site sediment transport relations. Unstable watersheds were those with increased SSY as result of land cover disturbances and/or channel reconfigurations. In the approach developed in Simon *et al.* (2004), watersheds were classified as stable or unstable using a field-based rapid geomorphic assessment technique, which was based on the channel evolution model (Simon and Hupp 1986; Simon 1989). Also for this study, measured

SSC over a range of flows were quantified into concentration-frequency and concentration-duration relationships, providing time-dependent sediment exposure measures (Simon and Klimetz 2008).

Sediment exposure measures quantified into concentration, frequency, and duration (CFD) relationships are essential to correlate with biotic response measures because elevated SSC are episodic in nature, and lotic ecosystems to some degree are resilient to episodic disturbances (Pringle *et al.* 1988; Allan and Castillo 2007; Schwartz *et al.* 2008). In the case for fish, biotic responses to elevated SSC appear to be dose dependent, where dose represents concentration times duration (Newcombe 2003). Prolonged periods of elevated SSC can cause fish mortality; depress growth, reproduction and recruitment; shift predator-prey relationships; and elicit avoidance behavior inducing out migration from impacted reaches (Newcombe and MacDonald 1991; Miner and Stein 1996; Newcombe and Jensen 1996; Servizi and Martens 1992; Waters 1995; DeRobertis *et al.* 2003). Indirectly, fish can be impacted by ecosystem tropic-level changes including a reduction of primary production and macroinvertbrate abundance (Berkman and Rabeni 1987; Ryan 1991; Waters 1995; Henley *et al.* 2000). Biotic responses to suspended sediment as a stressor are complex because they are dependent on: 1) both direct and indirect ecological effects as noted above, 2) species life histories, 3) species traits and differential tolerances; and 4) availability of habitat patch refugia. In addition, stream biological conditions in human-dominated watersheds are not singularly a function of a sediment stressor gradient, but multiple stressor gradients can occur (USEPA 2000c). A wide range of stressors is possible including: toxic pollutants, temperature, nutrient enrichment, hydromodification, habitat alteration, degraded riparian condition, and land cover changes (Wichert and Rapport 1998; Tong 2001; Sutherland *et al.* 2002; Rashleigh 2004).

Because of possible multiple stressors that can occur in human-dominated watersheds, finding biotic response measures that correlate with sediment stressor gradients is problematic (Walters *et al.* 2003; Nietch *et al.* 2005). In general, indices of biotic integrity are good for bioassessment, but are weak for identifying exposure-response relation (USEPA 2000c; Yuan and Norton 2004; Davies and Jackson 2006). Relying on species taxa, distribution, and abundance data can introduce undue variance into the linkage analysis, and fails to identify what ecological functions have potentially been lost along a stressor gradient (Grossman *et al.* 1985; Lamouroux and Souchon 2002). Poff *et al.* (2006) describes a conceptual framework whereby species are grouped into similar ecological and biological functional traits, in which these functional traits are expected to respond consistently along specific environmental gradients, both natural and stressor. Benefits of the functional traits approach to identifying biotic response measures include: 1) its applicability across biogeographical boundaries for ecoregion-scale analysis, 2) minimizing variability associated with biota richness and abundance, and sampling method and effort, and 3) reducing over influence of rare species in ecological analyses.

The functional traits approach builds on the ideas applied in a guild analysis, where a guild is defined as a group of species that exploit environmental resources in the same way (Begon *et al.* 1986; Simberloff and Dayan 1991; Wilson 1999). Common guilds used in ecological studies include feeding habits and spawning behavior, and can be

considered as autecological expressions satisfying basic biological needs for survival (Austen *et al.* 1994; Schwartz 2002; Grown 2004). Odom (1959) defines autecology as the ecology of individual species in relation to its environment. The functional traits concept described by Poff *et al.* (2006) couples the guild concept with the habitat template model of Southwood (1977), detailing traits in four main categories: ecological habit, organism behavior; life histories, and body morphology. Broadly applied to natural environmental gradients, functional traits influence fish distribution within watersheds for gradients such as basin area, elevation, and annual streamflow patterns (Poff and Ward 1989; Rahel and Hubert 1991; Poff and Allan 1995; Newall and Magnuson 1999). Fish distributions are also influenced by mesohabitat heterogeneity hierarchically structured by these watershed-scale gradients (Schwartz 1991; Aadland 1993; Poff *et al.* 1997; Lamouroux *et al.* 2004). Appling the functional traits concept along stressor gradients, several studies have successfully identified meaningful biotic response measures in benthic community biomonitoring studies (Doledec *et al.* 1999; Lamouroux *et al.* 2004; Bady *et al.* 2005; Tomanova *et al.* 2008; Tullos *et al.* 2009). Functional trait-based approaches have also been applied to fish communities as well, but analyses have focused on developing relationships for mesohabitat preferences rather than for watershed-scale stressors (Rabeni and Smale 1995; Vadas and Orth 2000; Blanck *et al.* 2007; Schwartz and Herricks 2008).

Independent of spatial scale, the functional traits concept appears useful in identifying ecological functions potentially lost along a stressor gradient. In the case of a sediment stressor gradient, it is argued that fish generally serve as the better organism group over benthic macroinvertebrates because of their life histories and mobility. Fish life spans typically range from one to five years, although a few species live much longer (Coker *et al.* 2001; Etnier and Starnes 2001; Holton 2003). Because elevated SSC are episodic, an organism with a longer life span has a greater temporal probability to be exposed to SSC levels that illicit a stressed biological response. Mobility is associated with life history patterns, such as movement towards headwaters during summer and downstream during winter for refugia in cold-climatic regions. Annual movement patterns increase the spatial probability of stressor exposure, although fish can move from locally unfavorable conditions. Fundamental to identifying possible exposure-biotic response relationships for sediment as a stressor, four functional trait groups appear relevant using fish; they are: preferred rearing habitat use, feeding trophic structure, feeding location habit, and spawning behavior.

4. METHODOLOGY

Three main data sources were used during the course of this study:

1. **Existing Precipitation, Flow and Sediment Data**
   Information and data regarding suspended-sediment and flow were obtained from U.S. Geological Survey (USGS) Web sites (http://water.usgs.gov) while precipitation data were obtained from National Oceanic and Atmospheric Administration (NOAA) Web sites (http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html). The data were initially sorted by Level III Ecoregion and placed in various matrices to examine spatial and temporal trends in the data, as well as to calculate 'reference' suspended-sediment yields and other metrics.

2. **Current and Historical Channel-Stability Conditions**
   Current channel-stability conditions were determined through field data collection at sites with existing flow and sediment data. Rapid Geomorphic Assessments (RGAs) were carried out to determine relative channel stability at USGS gauging-station locations with sufficient historical suspended-sediment and associated instantaneous-discharge data. Bed material was sampled at each location to determine relative embeddedness. For those sites where current stability conditions could not be related to historical sediment sampling, discharge-measurement data from the USGS were analyzed to determine trends of channel depth and width over time.

3. **Existing Fish Data**
   Fish data were obtained from a number of different sources:
   1) USEPA EMAP and REMAP datasets
   2) North Dakota Division of Health (NDDH)
   3) Dr. Charles Berry, USGS Coop Unit at South Dakota State University
   4) Montana Department of Fish, Wildlife and Parks (MFWP) online Fisheries Information System database:
   http://maps2.nris.state.mt.us/scripts/esrimap.dll?name =MFISH&Cmd=Main&Pc

   USGS gauging station locations were spatially correlated with fish sample locations by latitude and longitude coordinates. Presence/absence data were compiled per correlated USGS-fish data site to create a fish data matrix (USGS-Fish site x fish species presence/absence). Key basin variables, RGA scores, bed sediment and suspended-sediment characteristics were compiled for each USGS site (See data sources #1 and 2 above). This watershed/channel data formed the physical data matrix (USGS-Fish site x physical variables). In addition, autecological data were compiled for each of the fish species sampled, forming a third data matrix (Fish species x autecological attribute). Autecological data were complied from the following text references Coker *et al.* (2001), Etnier and Starnes (1993), Smith (1979); and on-line Search FishBase (www.fishbase.org)

and minor species on-line references. Autecological attributes included: mesohabitat preferences (open water, pool, riffle), feeding location (bottom, pelagic, surface), feeding behavior (grazing, sorting, stalking, pursuit), diet (algae, crustaceans, insects, fish, etc.); trophic level, spawning behavior (guarding, nest builder type, egg dispersion/laying type), and water quality tolerance. Using statistical ordination techniques, three main data matrices were used to examine patterns in fish assemblages associated with basin attributes, channel stability, and bed sediment and suspended sediment characteristics. Fish species presence/absence data was used to summarize occurrences of autecological attributes per USGS-Fish site, with the motivation to explore what ecological functions are lost due to channel stability and increased suspended dose levels.

4.1 Existing Precipitation, Flow and Sediment Data

There was a wide range of historical and current data available from various sources concerning flow and precipitation in the West and Midwestern United States. The majority of the flow and sediment data were downloaded from USGS Web sites. These data include:

1. suspended-sediment concentration, and associated instantaneous flow discharge,
2. annual peak discharge,
3. mean-daily flows,
4. summaries of instantaneous stream-flow measurements (USGS, 9-207 forms),
5. bed-material composition, and
6. precipitation.

(1) Suspended-sediment concentration and associated flow discharge at time of sampling were downloaded from USGS websites (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata) and used to develop relations between sediment transport and discharge over the range of flows at each site. These relations serve as the fundamental analytic unit for calculations of sediment-transport rates as concentrations (in milligrams per liter, mg/l), loads (in tonnes, T) and yields in tonnes per day (or year) per square kilometer.

(2) Annual peak discharges for the period of record at each station (Appendix A) were downloaded from USGS websites (http://nwis.waterdata.usgs.gov/usa/nwis/peak) and used to develop the frequency distribution of peak flows for each site. These data were then used to calculate the discharge of the 1.5 recurrence-interval flow and subsequently, to obtain the suspended-sediment load at in T/d at the $Q_{1.5}$. Dividing by basin area produced a suspended-sediment yield for the $Q_{1.5}$ in $T/d/km^2$.

(3) Mean-daily flows were downloaded for the period of record for each site from USGS websites (http://nwis.waterdata.usgs.gov/nwis/dv; Appendix A). Data for each day of record were used to determine the suspended-sediment load for that day (based on the sediment-transport relation) and summed for each year to obtain annual loadings values for each site. An average annual suspended-sediment load (in T/y) was obtained by summing all of the annual loads at a site and dividing by the number of years of complete record. An annual suspended sediment yield in $T/y/km^2$ was obtained by dividing by basin area.

(4) Summaries of instantaneous streamflow measurements made by the USGS for each site were used to determine relative stability conditions during periods of historical sampling. These summaries provide information on water-surface width, flow depth and gage height and other parameters for each discharge measurement. On average, between six and 10 measurements are made per year. Relations were established between flow depth and stage, and flow width and stage for decadal or shorter time periods to determine if these relations were changing with time. A shift in these relations provide evidence of historical instability and were used to sort sites into stable and unstable

groups where current geomorphic assessments had no bearing on geomorphic conditions during the period of sediment sampling.

(5) Where available, data on bed-material composition were downloaded from USGS Web sites where available and used for two purposes. First, these data as well as bed-material samples collected in the field were used to differentiate between "reference" conditions within specific ecoregions for streams dominated by different size classes (ie. silt/clay, sand, and gravel/cobble). Second, the data were used to calculate a measure of embeddedness for gravel-dominated streams (percent finer than 2mm) to investigate differences between stable and unstable streams in a specific ecoregion.

(6) Daily precipitation data were downloaded from NOAA Web sites (http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html) to evaluate trends over the past 100 years. Although these data were not used directly in calculations of suspended-sediment transport rates, in combination with water yield data (expressed as flow discharge per unit drainage area; m^3/km^2) they allowed for interpretations of changing flow regimes and land-use effects over the past century.

The methods used in this study follow a tested procedure aimed at developing defensible estimates of current sediment loads relative to "reference" suspended-sediment transport rates. A "reference" suspended-sediment transport rate is representative of stable streams within a specific ecoregion and can be defined as a concentration (in milligrams per liter; mg/l), a load (in metric tonnes per day or year; T/d or T/y) or a yield (in tonnes per day per square kilometer, $T/d/km^2$; or tonnes per year per square kilometer, $T/y/km^2$). Yield is one of the preferred parameters as it is independent of stream size, allowing the comparison of streams of different basin areas.

4.1.1 Suspended-Sediment Transport Rating Relations

Analysis of suspended-sediment transport data at each USGS gauging station involves establishing a relation between flow and sediment concentration, or load. Instantaneous-concentration data combined with either an instantaneous flow value or flow data representing the value obtained from the stage-discharge relation at 15-minute intervals are best. Mean-daily values of both flow and sediment loads, which are readily available from the USGS, tend to be biased towards lower flows, particularly in flashy basins. To establish sediment-transport rating relations, instantaneous concentration and 15-minute flow data were used from USGS gauging-station records (Appendix B, all rating relations given by this table pertain to one original regression). Simon (1989b) showed how the slope of sediment-transport relations varies over time and the course of fluvial adjustment. Kuhnle and Simon (2000) indicated that the coefficient of the rating relation may also be useful as a generalized measure of sediment-transport rates, particularly at low flows. It seems, however, that the suspended-sediment transport rate at the "effective discharge" may hold the greatest potential as a measure of sediment transport when comparing a large number of sites in a specific region. Although the effective discharge represents only one point along the transport relation, it can be viewed as an integration of the entire relation if we accept the time-based concepts implicit in its definition.

Suspended-sediment transport relations are empirical representations of the sediment-transport regime at a given gauging station location, reflecting geomorphic, hydraulic and other watershed processes operating upstream. It is acknowledged that these power functions tend to mask specifics of governing sediment-transport processes, yet they still provide a useful foundation for calculating the amount of suspended sediment being transported over a broad range of flows (four or five orders of magnitude in many cases; five in the example given in Figure 2). Because the relations between water discharge and suspended-sediment load or concentration are approximate, typically high coefficients of determination between these variables (for example 0.90) may still have order-of-magnitude 95% prediction limits. This is generally caused by the natural variability of sediment-transport processes, rather than due to error in the suspended-sediment measurements. Predictions of the rate of sediment transport at a particular place and time are, therefore, not exact. However, prediction of mean transport rates over a suitably long period of time (represented by a transport relation) should have a higher degree of reliability if a dataset has been collected over the range of flows. Therefore, this is a valid means of describing and comparing the suspended-sediment transport regimes for streams from a broad range of environments.

Using storm event data concerning discharge and load, a suspended-sediment transport rating equation was developed for each gauging station (Porterfield, 1972; Glysson, 1987; Simon, 1989b). Discharge was plotted against load in log-log space and a power function obtained by regression (Figure 2). In studies carried out in other ecoregions across the United States, trends of these data (in log-log space) often increase linearly and then break off and increase more slowly at high discharges. Preliminary analyses show that although sand concentrations continue to increase with discharge, the silt-clay fraction attenuates, causing the transport relation to flatten (Kuhnle and Simon, 2000).

This change in slope may also be indicative of stages where flow begins to spread out across the flood plain surface. To alleviate this problem, a second (or even third) linear segment (in log-log space) is often fit with the upper end of the dataset (Simon, 1989b; Figure 3). The break in slope is determined visually, however 'trend-lines' for each 'set' of data must meet between the datasets.

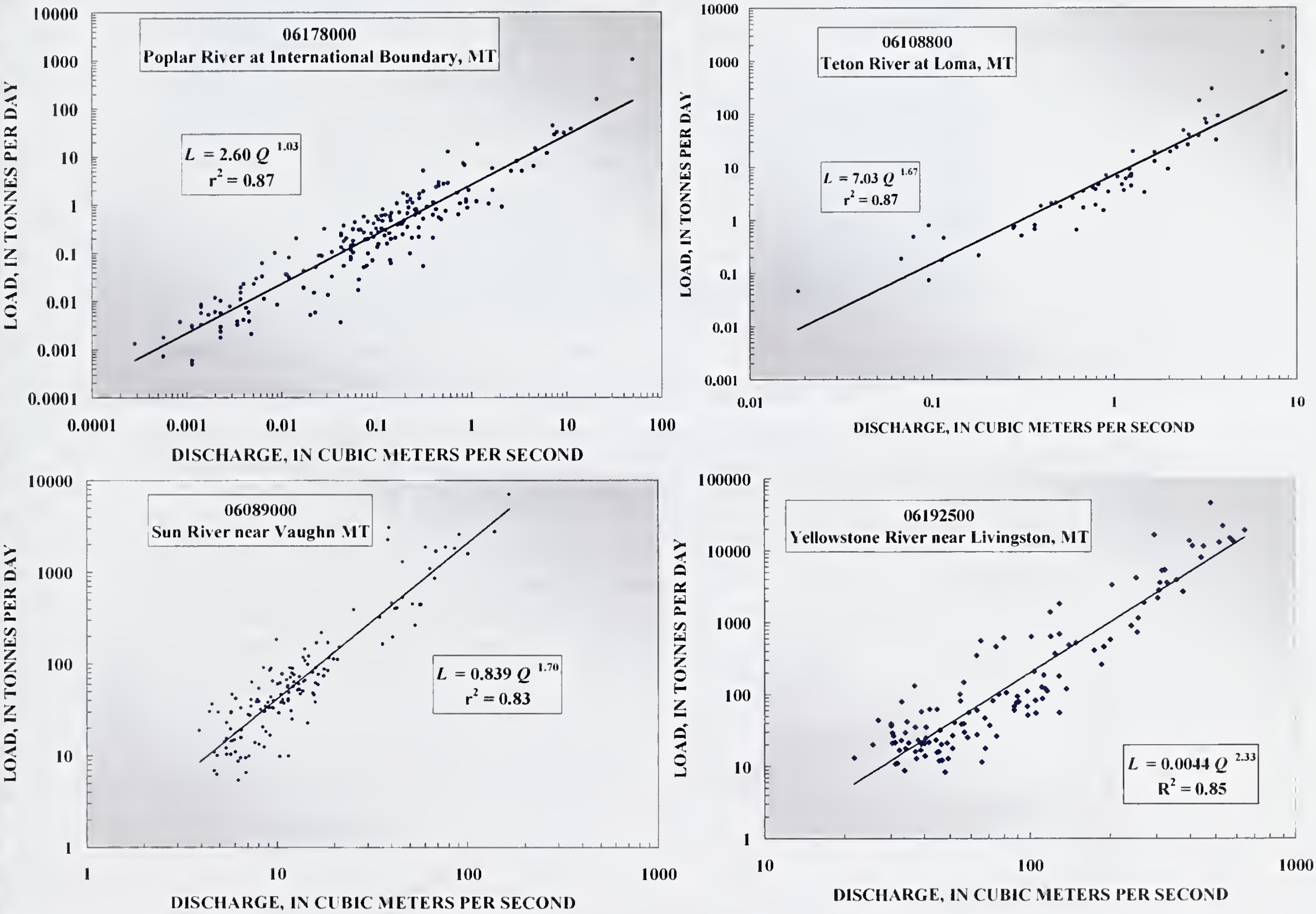

Figure 2 – Rating equations for various gauging stations in Montana, Ecoregion 42.

To examine the validity of using two linear segments (instead of a single power function) to 'predict' suspended-sediment transport at a site, the residuals representing the difference between predicted and observed load values are calculated. An optimum relation would show no trend in the residuals (flat slope). Conversely, a trend in residuals indicates either an under- or over-estimation of load values. This technique was used to determine whether a single, double, or triple segmented relation was to be used for a specific site (Figure 4). Adjustments to the upper end of the rating directly addresses one of Nash's (1994) concerns regarding the use of a single power function to describe the relation between flow and suspended-sediment discharge over the entire range of flows.

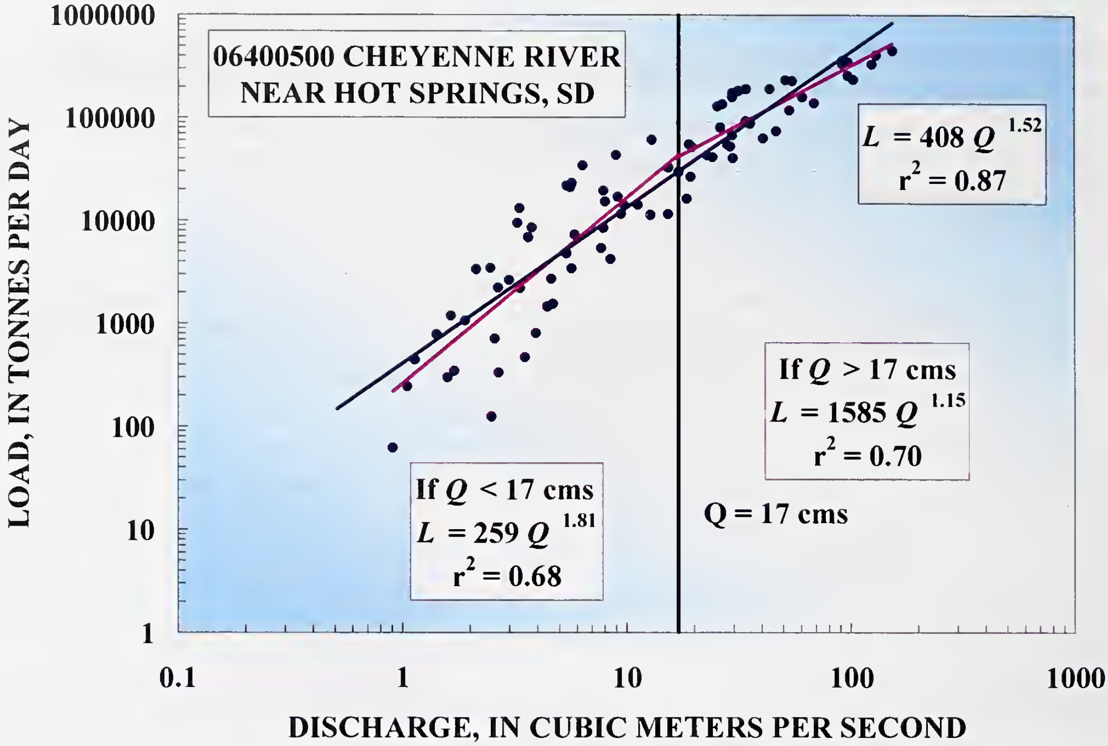

Figure 3 – A rating with two linear segments is used to describe suspended-sediment transport at the Cheyenne River near Hot Springs, SD (pink line) as opposed to a single power function (blue) which over estimates loads at low discharges and underestimates loads at high discharges.

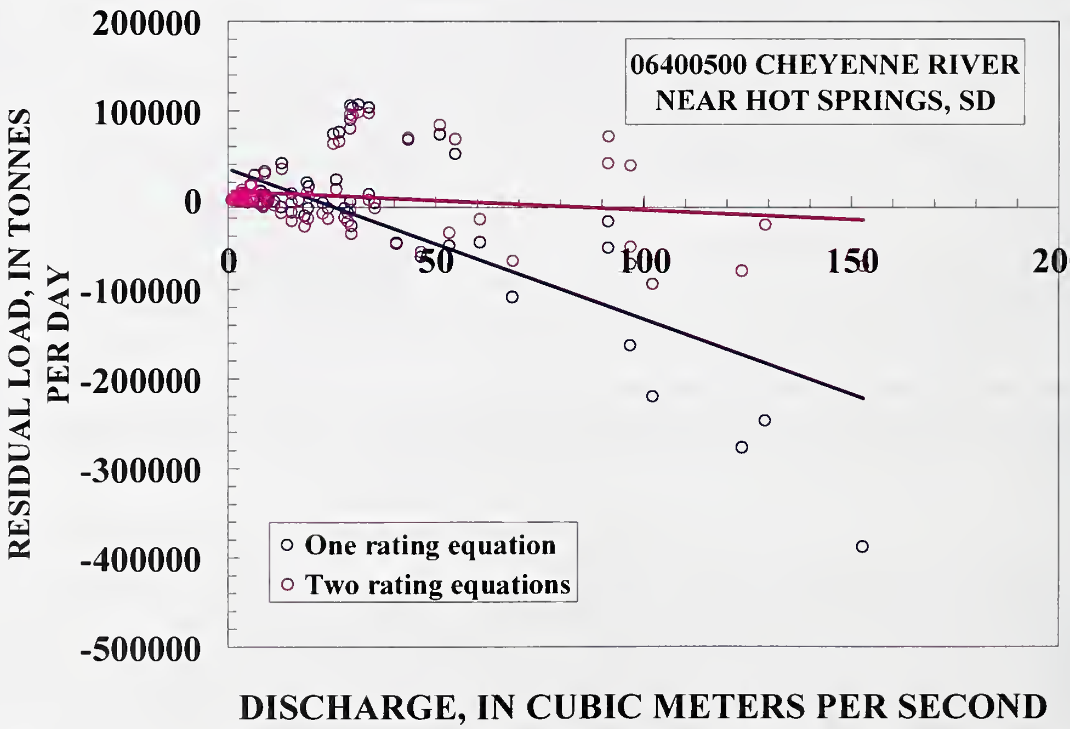

Figure 4 – Load residuals for site 06400500 using a single power function (blue line) and with two linear segments (pink line). Note that the trend of residuals using the two-linear segments is much flatter (indicating a better 'model' than the trend of residuals using a single power function (black line).

4.1.2 Calculating Suspended-Sediment Load at the $Q_{1.5}$

As described in Section 3.1, the $Q_{1.5}$ was used as a surrogate for the effective discharge in this study (Simon *et al.* 2004a). This was calculated from a log-Pearson Type III distribution using the annual-maximum peak-flow series for each of the sites with available data. The example shown in Figure 5 is for the Yellowstone River at Billings, MT (Ecoregion 43), where the $Q_{1.5}$ was determined to be 985 m^3/s. Suspended-sediment yield at the $Q_{1.5}$ was obtained by using the sediment-transport relation developed for the site, substituting the $Q_{1.5}$ into the relation and solving for load. Dividing by drainage area produces sediment yield (Figure 6). The rating equation was also used to create daily yield values in tonnes per day from mean-daily discharge data. Mean-daily loads were summed for any given *complete* calendar year, providing a mean annual load (T/y). To normalize data for watersheds of different size, sediment load was divided by drainage area, providing calculations of mean annual sediment yield ($T/y/km^2$). This provides a measure of the annual mass of suspended-sediment transported past a site, per unit of area. Because sediment-transport data are generally non-normally distributed, quartile measures were used to describe data ranges and central tendencies.

As part of the analytic procedure, the maximum sampled discharge is compared to the $Q_{1.5}$ to make sure that it falls within the flow range sampled. If the $Q_{1.5}$ is exceeds the maximum sampled discharge by 50%, the site is not used in further analysis. This is because considerable error can occur in calculating loads high flows, particularly if the sediment-transport relation is extended beyond the measured bounds of the data. In the example shown in Figure 5 for the Yellowstone River at Billings, MT, the maximum sampled discharge was 1420 m^3/s, indicating that the upper-end of the transport relation is relatively well defined.

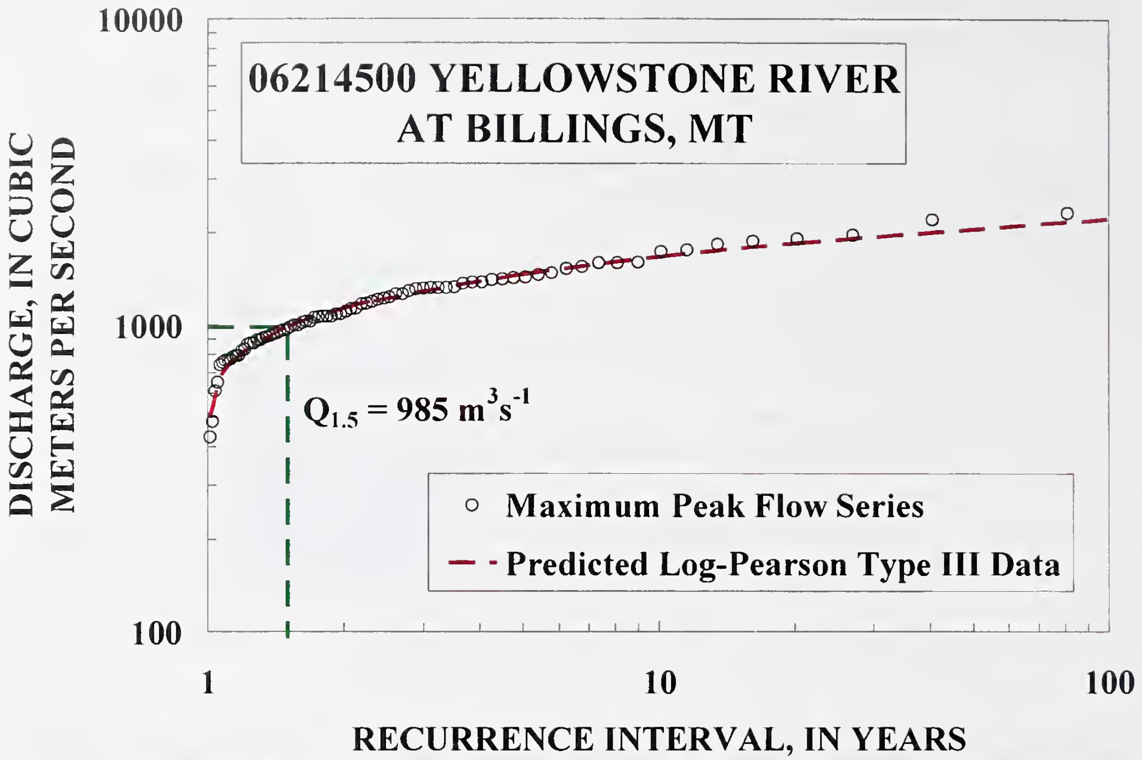

Figure 5 - Flood frequency distribution for the Yellowstone River at Billings, MT, Ecoregion 43, as calculated from the annual maximum series. The graph shows predicted values to be a reasonable estimate of observed peak flow measurements.

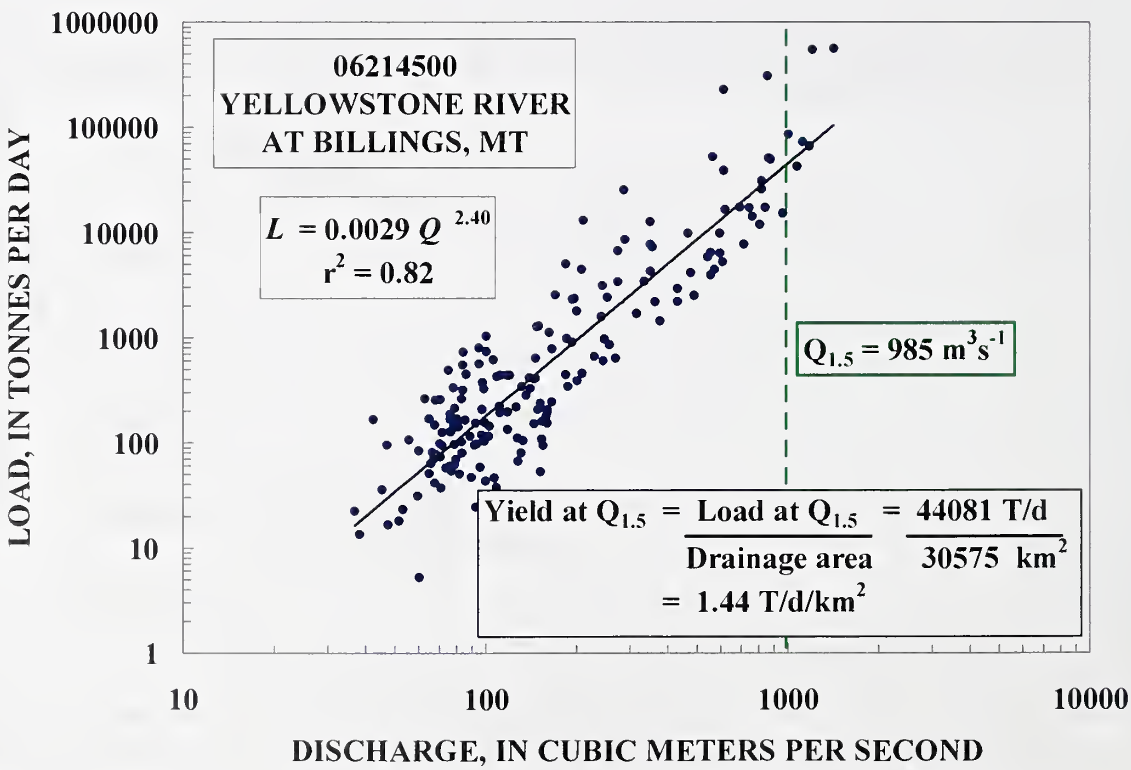

Figure 6 – Suspended-sediment transport rating for the Yellowstone River at Billings, MT, Ecoregion 43 showing how suspended-sediment yield is obtained for the $Q_{1.5}$. The vertical green line indicates the $Q_{1.5}$ of 985 m^3/s.

4.1.3 Frequency, Duration and Dosage: Suspended-Sediment Metrics for Potential Analysis with Biotic Data

While annual suspended-sediment yields and those at the $Q_{1.5}$ are important when considering stream stability and have been used to develop targets for sediment, they may be of little significance to life-cycle processes of aquatic biota found within that stream. In this case it might be more appropriate to consider the frequency of a given concentration and/or the duration that a given concentration is sustained (Newcombe, *et al.*, 1991; 1996). The hypothesis here is that stable, 'reference' streams will have fewer high-concentration events and when those events do occur, the duration will be shorter than in unstable streams.

With this in mind, suspended-sediment concentrations (in mg/l) were calculated from mean-daily flow data for each day of flow record. The data were then sorted by daily value and assigned a percentile based on the complete distribution. A frequency distribution much like the ones typically used to describe flow, based on the percentage of time that given concentrations were equaled or exceeded was then developed for each site. A 99.99 percentile (exceedance) value represents a very low concentration that is equaled or exceeded 99.99 percent of the time. Conversely, an exceedance value of 1 represents a relatively high concentration that is exceeded, on average, about 1% of the time. An example is shown from the Little White River, SD in Figure 7.

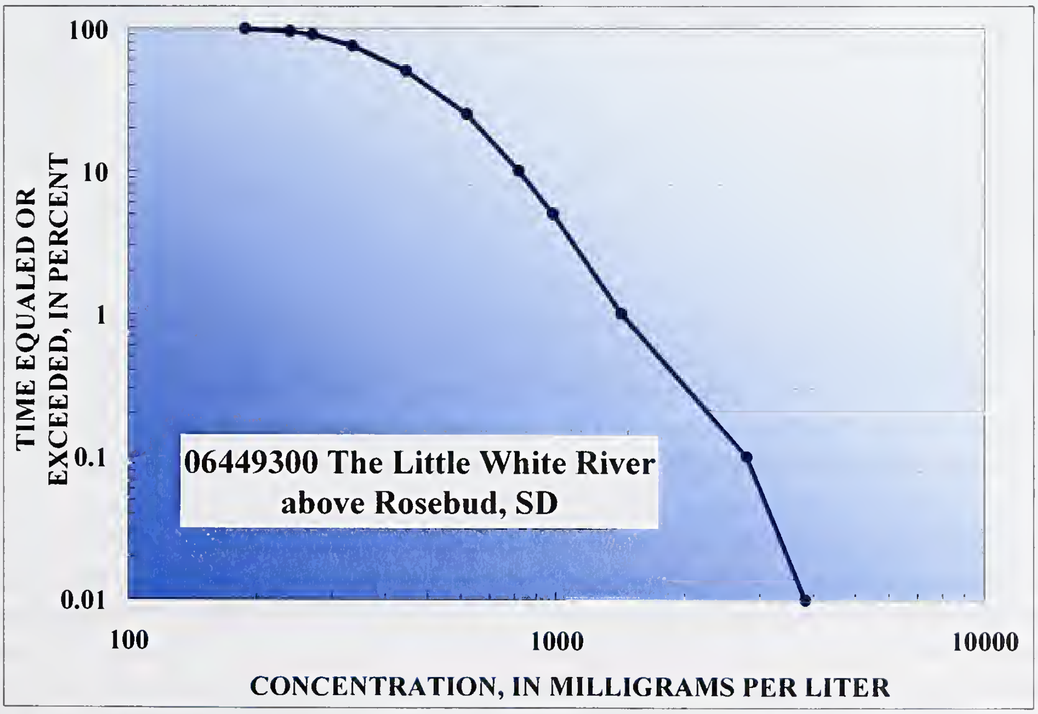

Figure 7 –Example frequency distribution for concentrations for the Little White River above Rosebud, SD, showing the percentage of time given concentrations were equaled or exceeded.

To obtain sediment metrics representing the duration a given concentration is maintained or exceeded, a simple Excel macro was created within the spreadsheet database to count

the number of consecutive days a given concentration was equaled or exceeded (Figure 8). In this way both magnitude-frequency and magnitude-duration can be examined in terms of geomorphic stability to test whether the frequencies and durations of suspended-sediment concentration events in stable, unimpaired streams can be differentiated from those in unstable, impacted streams. This was carried out for the period of record for all sites that had sufficient suspended-sediment data (more than 15 samples) and that had more than five complete years of mean-daily flow data.

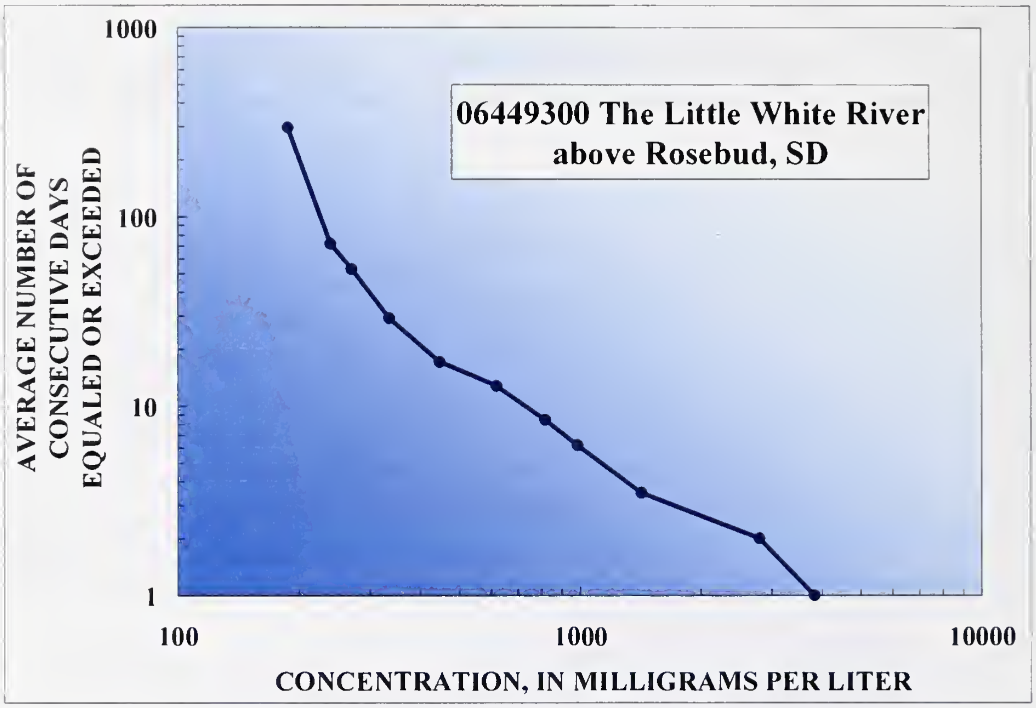

Figure 8 – Magnitude-frequency duration of concentrations for the Little White River above Rosebud, SD. The average number of consecutive days a given concentration is equaled or exceeded.

Frequency-magnitude and duration data were also computed for "fish exposure" months only; March through November. Frequency-magnitude and duration data represents a suspended sediment dose and frequency of this dose (concentration x duration) during a period in which fish are feeding and spawning. Survival of sight-orientated fish insectivores and piscivores could be impacted frequency of suspended sediment dose, however herbivore and sorting bottom feeders likely would not be impacted by dose. Fish recruitment could be impacted by frequency of suspended sediment dose if embeddedness is increased for spawners that build gravel nests. However, non-guarding fish spawners that disperse eggs into the open water may benefit from increased suspended sediment dose preventing predators from finding eggs. Because feeding and spawning are predominant during non-winter months, dose was used as the suspended sediment metric of interest to examine potential impacts to fish community structure. Suspended sediment dose was only one metric that was used in the ecological analysis.

The product of sediment concentration and duration that concentration is equaled or exceeded is termed "dosage" and has been found to be a relevant parameter in studies of the effects of a given pollutant on aquatic biota (USEPA, 2002b; Newcombe, 2003;

Schwartz *et al*., 2008). Dosage was calculated for the range of concentrations at each site by multiplying a concentration by the number of days of continuous duration. This was done over the entire range of concentrations and resulted in a distribution for dosage for each site (Figure 9). Values plotted on the left side of the figure represent infrequent, high-concentration events with frequent, low-concentration events plotting to the right. In the example shown in Figure 9, and ignoring the lowest concentrations (shaded-out in gray; as they represent background, low-flow transport rates), this indicates that the potentially most-critical dosages are those that are exceeded between 0.1 and 10% of the time (represented in red in Figure 9).

These dosage distributions were then sorted into stable and unstable sites to differentiate between general differences in sediment dosage by ecoregion. The distribution of differences between ecoregion-level dosages for stable and unstable streams was termed "dose impact" and provides a means of comparing sediment impacts to biota. In fact, the dosage distribution from an unstable site could be used to evaluate the relative degree of impact by sediment if we consider the dosage distribution for stable streams within an ecoregion as its 'reference' condition.

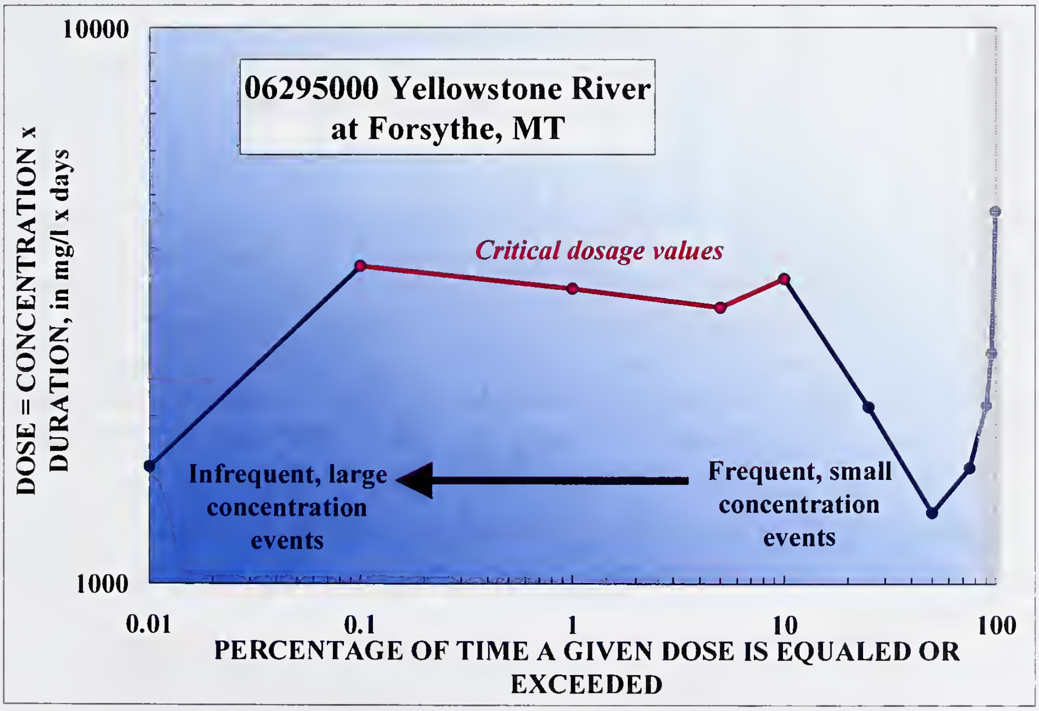

Figure 9 – Concentration dosage calculated for the Yellowstone River at Forsythe, MT by multiplying concentration by the number continuous days it was equaled or exceeded. Red highlighted dose values represent dosages considered to be the most-critical.

All of the fundamental parameters (metrics) discussed above, whether downloaded and analyzed from historical USGS records or calculated from other available information were compiled into a matrix for each Level III Ecoregion within EPA Region 8. These data were then organized to enable further sorting based on relative channel stability, dominant bed-material class, drainage basin area, and in some cases, into Level IV (smaller) Ecoregions.

4.1.4 Trends in Precipitation and Flow over the Past 100 Years

All previously downloaded annual-peak flows and mean-daily flow data were gathered by Level III Ecoregion to examine historical trends in flow and precipitation. Mean-daily flow data for each site were averaged for each year to produce a record of the annual, mean-daily discharge over time. Results for each year were divided by drainage area to obtain an annual mean-daily "water yield" so that trends for basins of varying size could be compared for the last 100 years (Figure 10). Appendix A provides the period of mean-daily flow data for each site and the number of complete calendar years of data. This is summarized for each Level III Ecoregion in Table 4. It is important to note that all available flow data were used for examining historical trends, whereas sediment-yield data were not calculated for sites with less than five complete years of flow data.

An average water yield each year was then calculated from all sites within a given ecoregion to produce a region-wide trend over the past century for both mean-daily discharge and the annual peak flow discharge. Trends in water yield over the past 100 years provide a means of integrating the effects of changes in rainfall-runoff regime as a result of climate change and anthropogenic disturbances such as land use changes and dam construction. A similar analysis was conducted using peak-flow data for each site (Appendix A), thereby providing trends in peak water yield for each ecoregion over the last 100 years.

To examine how trends in precipitation may have varied over the past 100 years and how these trends have affected water yields (irrespective of anthropogenic influences), precipitation data across EPA 8 were obtained. Monthly precipitation data were summed for each year of record, and an average annual precipitation calculated for each Level III Ecoregion for the period of record. Data were also organized by month so that an average precipitation value could be calculated for each month as a time series (for example, January 1900, January 1901, January 1902), and for each month for the period of record.

Table 4 – Number of sites with instantaneous peak flow, mean-daily flow and precipitation data.

Ecoregion	Number of sites with peak flow data	Number of sites with mean daily data	Number of sites with precipitation data
15	15	15	12
17	45	42	22
42	34	34	19
43	152	146	33
46	29	30	24
48	16	14	8

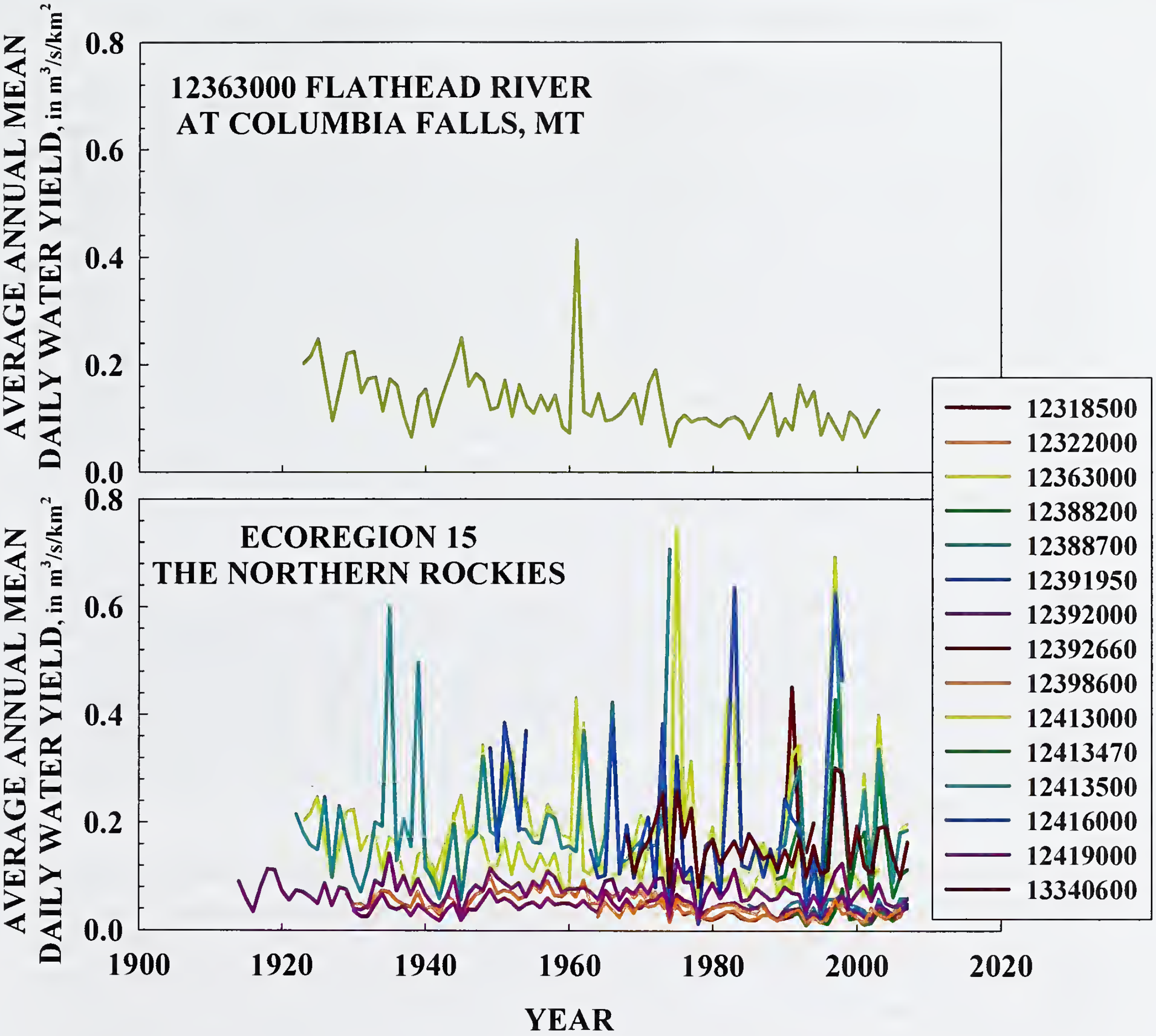

Figure 10 – Annual mean daily water yield data for Ecoregion 15, the Northern Rockies.

4.2 Field Data Collection

4.2.1 Establishing Current 'Reference' Conditions

Rates and concentrations of suspended-sediment transport vary over time and space in response to factors such as precipitation characteristics and discharge, geology, relief, land use and channel stability, among others. There is no reason to assume that "natural" or background rates of sediment transport will be consistent from one region to another. Within the context of clean-sediment TMDLs, it follows that there is no reason to assume then that "target" values should be consistent on a nationwide basis. Similarly, there is no reason to assume that channels within a given region will have consistent rates of sediment transport. For example, unstable channel systems or those draining disturbed watersheds will produce and transport more sediment than stable channel systems in the same region. This reflects differences in the magnitude and perhaps type of erosion processes that dominate a sub-watershed or stream reach.

To identify those sediment-transport conditions that represent impacted or impaired conditions, it is essential to first be able to define non-disturbed, stable, or 'reference' conditions. For the purposes of this study, stability is defined in geomorphic terms; that is, a stream in dynamic equilibrium, capable of transporting all sediment delivered to the system without altering its dimensions over a period of years. This is not to say that the stream is static but that short-term, local processes of scour and fill, erosion and deposition, are balanced through a reach such that the stream does not widen, narrow, degrade or aggrade.

Consider the stream as the information super highway of the watershed where all energy and materials emanating from the watershed and upstream tributaries are routed and transported. If there is excess energy relative to the amount and caliber of sediment being delivered from upstream, the channel will erode. If the converse is true, the channel will deposit. If however, there is a general balance between flow energy and the upstream delivery of sediment the channel will be stable, representing a system where the stream is in balance or equilibrium with its contributing watershed area and upstream reaches. Thus the condition of the channel at a particular reach is a synthesis of the flow and sediment transport processes upstream from it.

This process-based definition of "reference" is used to develop consistent field and analytic procedures for identifying stable alluvial channels. Because this definition does not rely on a specific channel shape or form, it is flexible for the diverse range of fluvial environments that are encountered on the landscape and does not impose preconceived notions of what a "reference" channel should look like. In fact, these concepts of "reference" are similar to US EPA's "least disturbed" concept of "reference". These working definitions of reference and target conditions have been used successfully to define "background", "reference" or target sediment-transport rates for streams across the United States (Simon et al., 2004; Simon and Klimetz 2008a; 2008b).

4.2.2 Rapid Geomorphic Assessments: RGA's

To evaluate channel-stability conditions and stage of channel evolution of a particular reach, an RGA was carried out at each site using the Channel-Stability Ranking Scheme. RGAs utilize diagnostic criteria of channel form to infer dominant channel processes and the magnitude of channel instabilities through a series of nine unique criteria. Granted, evaluations of this sort do not include an evaluation of watershed or upland conditions; however, stream channels act as conduits for energy, flow and materials as they move through the watershed and will reflect a balance or imbalance in the delivery of sediment. Given the large number of USGS gages in EPA Region 8, it was not feasible to perform detailed, time consuming field surveys at every site, RGAs provided an efficient alternative, enabling the rapid characterization of stability conditions.

Four steps are completed on site:

1. Determine 'reach'. The 'reach' is described as the length of channel covering 6-20 channel widths, thus is scale dependent and covers at least two pool-riffle sequences.
2. Photograph the reach, for quality assurance and quality control purposes. Photographs are used with RGA forms to review the field evaluation
3. Carry out RGA. Make observations of channel conditions and diagnostic criteria listed by the channel-stability ranking scheme (Figure 11).
4. Sample bed material.

CHANNEL-STABILITY RANKING SCHEME

River________________________ Site Identifier__________________________________

Date ____________ Time_______ Crew ______________ Samples Taken________________

Pictures (circle) U/S D/S X-section Slope__________ Pattern: Meandering / Straight / Braided

1. Primary bed material

	Bedrock	Boulder/Cobble		Gravel	Sand	Silt Clay	
	0	1		2	3	4	____

2. Bed/bank protection

	Yes	No	(with)	1 bank protected	2 banks		
	0	1		2	3		____

3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)

	0-10%	11-25%	26-50%	51-75%	76-100%		
	4	3	2	1	0		____

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

	0-10%	11-25%	26-50%	51-75%	76-100%		
	0	1	2	3	4		____

5. Stream bank erosion (Each bank)

	None	Fluvial	Mass wasting (failures)	
Left	0	1	2	____
Right	0	1	2	____

6. Stream bank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	0	0.5	1	1.5	2	____
Right	0	0.5	1	1.5	2	____

7. Established riparian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	____
Right	2	1.5	1	0.5	0	____

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	____
Right	2	1.5	1	0.5	0	____

9. Stage of channel evolution

	I	II	III	IV	V	VI	
	0	1	2	4	3	1.5	____

Figure 11 – Channel stability ranking scheme used to conduct rapid geomorphic assessments (RGAs). The channel stability index is the sum of the values obtained for the nine criterion.

4.2.3 Channel-Stability Index

A scheme that assesses nine unique criteria was used to record observations of field conditions during RGAs (Figure 11). Each criterion was ranked from zero to four and all values summed to provide an index of relative channel stability. The higher the number the greater the instability: sites with values greater than 20 exhibit considerable instability; stable sites generally rank 10 or less. Intermediate values denote reaches of moderate instability. However, rankings are not weighted, thus a site ranked 20 is not twice as unstable as a site ranked 10. The process of filling out the form enables the final decision of 'Stage of Channel Evolution'.

Characterizing Channel Geomorphology

1. Primary bed material

Bedrock	The parent material that underlies all other material. In some cases this becomes exposed at the surface. Bedrock can be recognized by appearing as large slabs of rock, parts of which may be covered by other surficial material.
Boulder/Cobble	All rocks greater than 64 mm median diameter.
Gravel	All particles with a median diameter between 64.0 – 2.00 mm
Sand	All Particles with a median diameter between 2.00 – 0.062 mm
Silt Clay	All fine particles with a median diameter of less than 0.062 mm Grain size classification given by Knighton (1998) p. 107.

2. Bed/bank protection

Yes	Mark if the channel bed is artificially protected, such as with rip rap or concrete.
No	Mark if the channel bed is not artificially protected and is composed of natural material.
1 bank protected	Mark if one bank is artificially protected, such as with rip rap or concrete.
2 banks	Mark if two banks are artificially protected.

3. Degree of incision (Relative elevation of "normal" low water)
   Assume top-bank elevation represents the 100% elevation and the thalweg represents 0% elevation, select the relative elevation of "normal" low water.

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)
   Often only found where obstructions or artificial protection are present within the channel. Taking the reach length into consideration, channel width at the upstream and downstream parts of the constriction are measured and the relative difference calculated.

5. Stream bank erosion (Each bank)
   The dominant form of bank erosion is marked separately for each bank, left and right, facing in a downstream direction.
   If the reach is a meandering reach, the banks are viewed in terms of 'Inside, Outside' as opposed to 'Left, Right' (appropriate for questions 5-8). Inside bank, being the inner bank of the meander, if the stream bends to the left as you face downstream, this would be the left bank. Outside bank, being the outer bank, on your right as you face downstream in a stream meandering left.

None	No erosion
Fluvial	Fluvial processes (i.e. undercutting of the bank toe), cause erosion.
Mass Wasting	Mass movement of large amounts of material from the bank is the method of bank erosion. Often characterized by high, steep banks with shear bank faces. Debris at the bank toe appears to have fallen from higher up in the bank face. Includes, rotational slip failures and block failures.

6. Stream bank instability (Percent of each bank failing)
   If the bank exhibits mass wasting, mark percentage of bank with failures over the length of the reach. If more than 50% failures are marked, the dominant process is mass wasting (see question 5).

7. Established riparian woody-vegetative cover (Each bank)
   Riparian vegetative cover refers to perennial vegetation that grows on the streambanks. This was originally defined as including only trees and shrubs but was revised to include perennial grasses.

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)
   The percentage of the reach length with fluvial deposition of material (often sand, also includes fines and gravels) is marked.

9. Stage of channel evolution
   Stages of channel evolution are given by Simon and Hupp, 1986 (see diagram below). All of the above questions help lead to an answer to this question. Refer to previously determined criterion for guidance. See Table 5 for guidelines of features often found with each stage of channel evolution.

Total Score Total up the responses to the 9 questions.

4.2.4 Stages of Channel Evolution

The channel evolution framework set out by Simon and Hupp (1986) is used by TMDL practitioners to assess the stability of a channel reach (Figure 12; Table 5). With stages of channel evolution tied to discrete channel processes and not strictly to specific channel shapes, they have been successfully used to describe systematic channel-adjustment processes over time and space in diverse environments, subject to various disturbances such as stream response to: channelization in the Southeast US Coastal Plain (Simon, 1994); volcanic eruptions in the Cascade Mountains (Simon, 1999); and dams in Tuscany, Italy (Rinaldi and Simon, 1998). Because the stages of channel evolution represent shifts in dominant channel processes, they are systematically related to suspended-sediment and bed-material discharge (Simon, 1989b; Kuhnle and Simon, 2000), fish-community structure, rates of channel widening (Simon and Hupp, 1992), and the density and distribution of woody-riparian vegetation (Hupp, 1992).

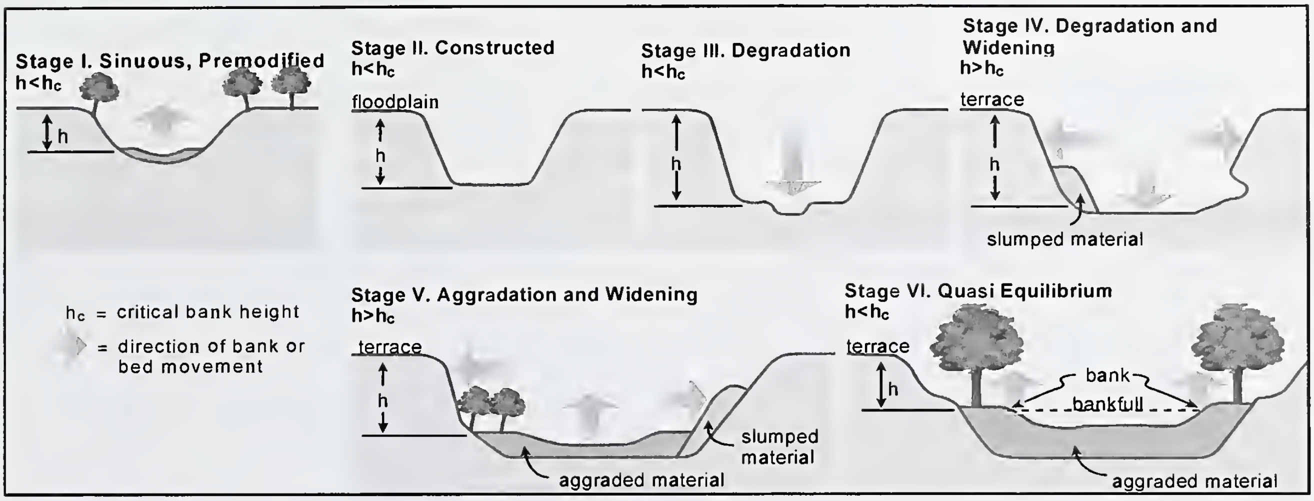

Figure 12 – Six stages of channel evolution from Simon and Hupp (1986) and Simon (1989a) identifying Stages I and VI as 'reference' channel conditions (See Table 5 for explanation of stages).

Table 5 – Summary of conditions to be expected at each stage of channel evolution.

Stage	Descriptive Summary
I	*Pre-modified* – Stable bank conditions, no mass wasting, small, low angle bank slopes. Established woody vegetation, convex upper bank, concave lower bank.
II	*Constructed* – Artificial reshaping of existing banks. Vegetation often removed, banks steepened, heightened and made linear.
III	*Degradation* – Lowering of channel bed and consequent increase of bank heights. Incision without widening. Bank toe material removed causing an increase in bank angle.
IV	*Threshold* – Degradation and basal erosion. Incision and active channel widening. Mass wasting from banks because bank heights exceed the critical conditions (geotechnical strength) of the bank material. Leaning and fallen vegetation. Vertical face may be present.
V	*Aggradation* – Deposition of material on bed, often sand. Widening of channel through bank retreat; no incision. Concave bank profile. Filed material re-worked and deposited. May see floodplain terraces. Channel follows a meandering course.
VI	*Restabilization* – Reduction in bank heights, aggradation of the channel bed. Deposition on the upper bank therefore visibly buried vegetation. Convex shape. May see floodplain terraces.

An advantage of a process-based channel-evolution scheme for use in TMDL development is that Stages I and VI represent true 'reference' conditions. In some cases, such as in the Midwestern United States where land clearing activities near the turn of the 20th Century caused massive changes in rainfall-runoff relations and land use, channels are unlikely to recover to Stage I, pre-modified conditions. Stage VI, a re-stabilized condition, is a much more likely target under present regional land use and altered hydrologic regimes (Simon and Rinaldi, 2000) and can be used as a 'reference' condition. Stage VI streams can be characterized as a 'channel-within-a-channel', where the previous floodplain surface is less frequently inundated and can be described as a terrace. This morphology is typical of recovering and re-stabilized stream systems following incision. In pristine areas, where disturbances have not occurred or where they are far less severe, Stage I conditions can be appropriate as a reference.

4.2.5 Determining Historical Channel Stability

Suspended-sediment sampling was carried out over fifty years ago at many sites; therefore current channel stability conditions may be different to at those during the time of suspended-sediment sampling. Plotting certain stream morphology characteristics against a range of discharges over time can help us to establish channel stability during the period of suspended-sediment sampling, as it is both expensive and time consuming to establish current transport-ratings. Figure 13 provides an example of using USGS stream-flow measurements to estimate channel stability at time of suspended-sediment sampling. A 2007 RGA judged the channel at station 06355500 on the North Fork Grand River near White Butte, SD to be unstable. Stream-flow measurement data was analyzed for this site as suspended-sediment sampling was carried out between 1949 and 1951, therefore current stability conditions of this channel may mean very little to the stability conditions fifty years ago. Analysis of stream-flow measurement data shows no bed movement during the time of suspended-sediment sampling, thus this channel is considered stable during that period. The stream-flow measurements at this station also support the present RGA, as the channel has exhibited continual incision since the early 1960s.

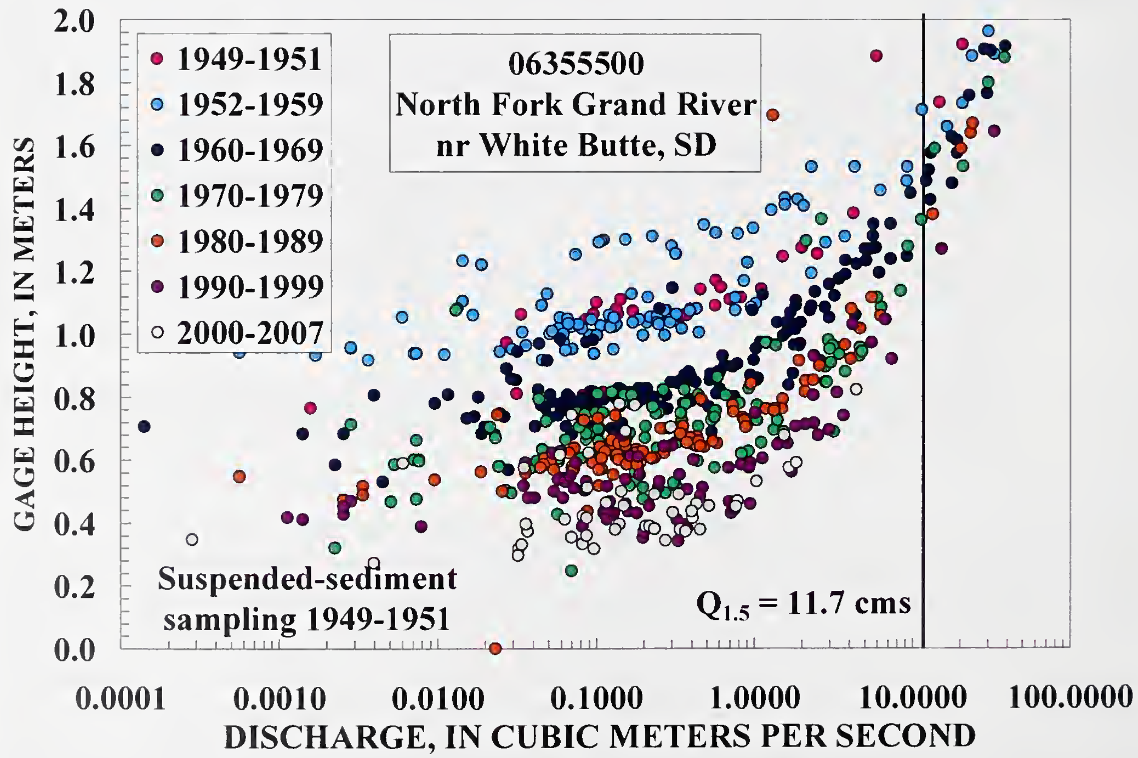

Figure 13 – Stream-flow measurements for the North Fork Grand River near White Butte, SD in Ecoregion 43 show that while the channel has degraded consistently since the early 1960s, it was relatively stable during the period of suspended-sediment sampling, 1949 to 1951.

Stream-flow measurements were also analyzed for the Souris River near Sherwood, ND in Ecoregion 46. Photographs show outside bend mass wasting in 2007, therefore this channel is currently considered unstable (Figure 14). However stream-flow measurement data show no bed movement between 1974 and 1981 (Figure 15), the period of suspended-sediment sampling, therefore the channel is thought to have been stable at this time.

Figure 14 – Present RGAs show mass wasting on both the inside and outside banks on the Souris River near Sherwood, ND gage 05114000, characteristics of an unstable channel.

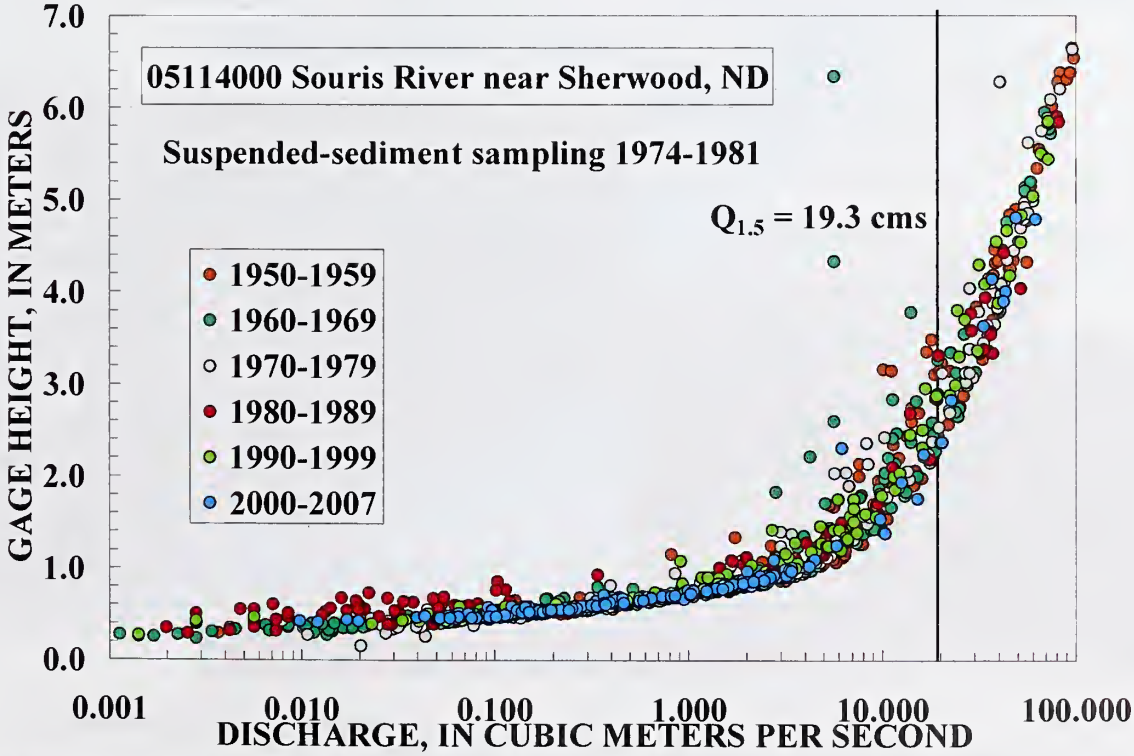

Figure 15 – Stream-flow measurement data for the Souris River near Sherwood, ND gage 05114000, show very no changes in bed elevation during the period of suspended-sediment sampling.

Stream-flow measurement data can also indicate aggradational channel beds, as is the case for the White River near Oacoma, SD gage # 06452000 in Ecoregion 43 (Figure 16). An aggradational channel with eroding banks is considered an unstable channel; stage V in the Channel of Evolution Model.

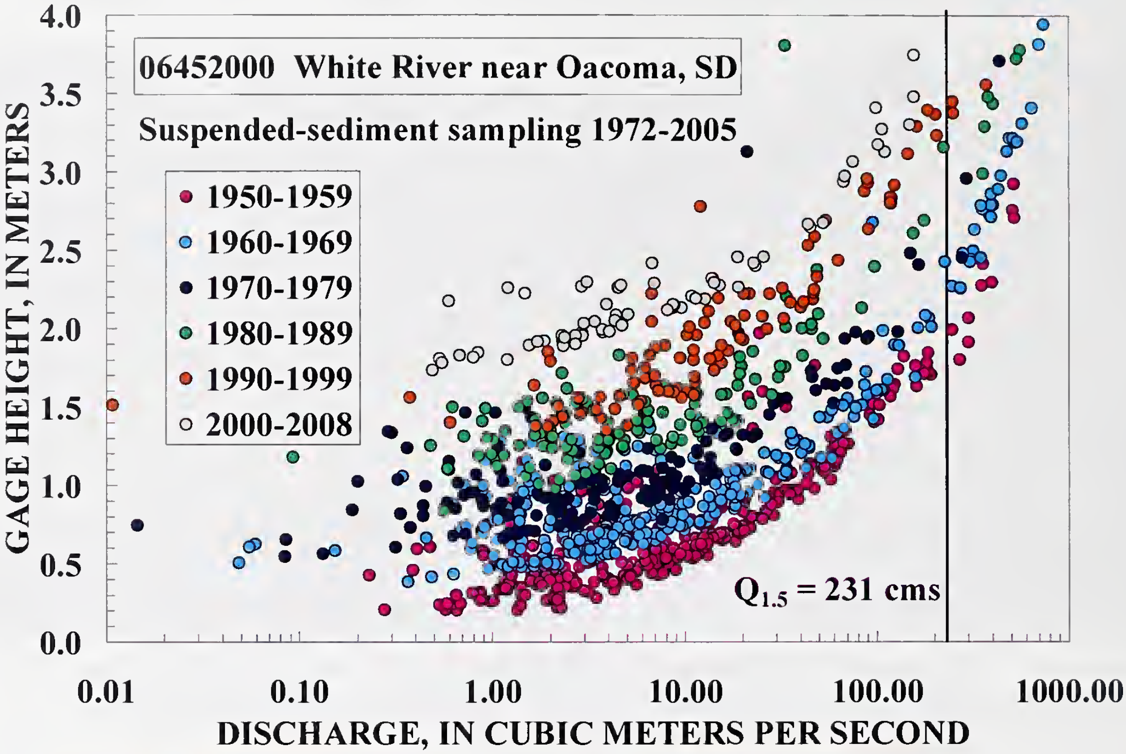

Figure 16 – The White River near Oacoma, SD is an aggradational channel with unstable banks, filling approximately 2 m since the 1950s.

Another method of determining historical stability was to examine suspended-sediment sample data over a range of years, where long periods of record exist. For example, suspended-sediment was sampled between 1972 and 2005 at the White River near Oacoma. Analyzing the suspended-sediment data by decade shows a gradual increase in rating exponent and a decrease in coefficient (Figure 17). These changes in rating relation implies channel adjustments with time to generally lower sediment transport rates as the lines shift downwards. Alternatively, no change in rating equation with time can suggest a stable channel, as is the case at the Belle Fourche River below Moorcroft, WY (Figure 18). This analysis must be used in conjunction with analysis of stream-flow measurement data that provides a mechanism for determining changes in channel form over time (See Figure 16).

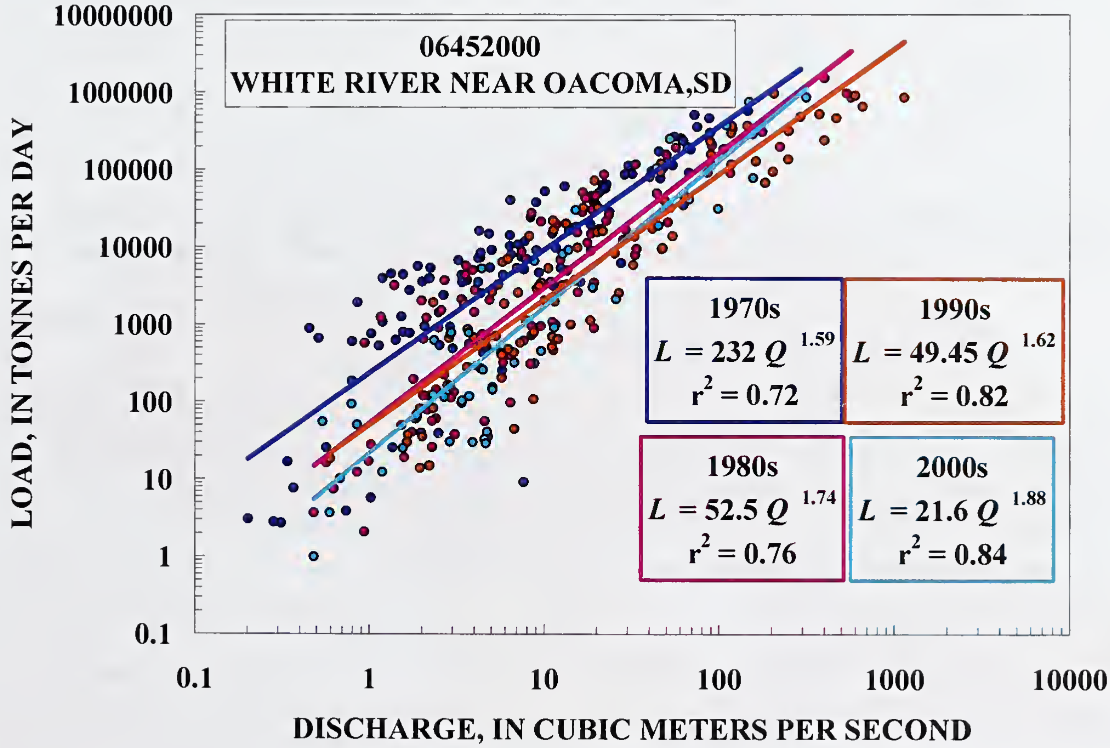

Figure 17 – Changes in suspended-sediment transport relations with time implies channel instability. Note: Color of dots is associated with color of text boxes for a given decade.

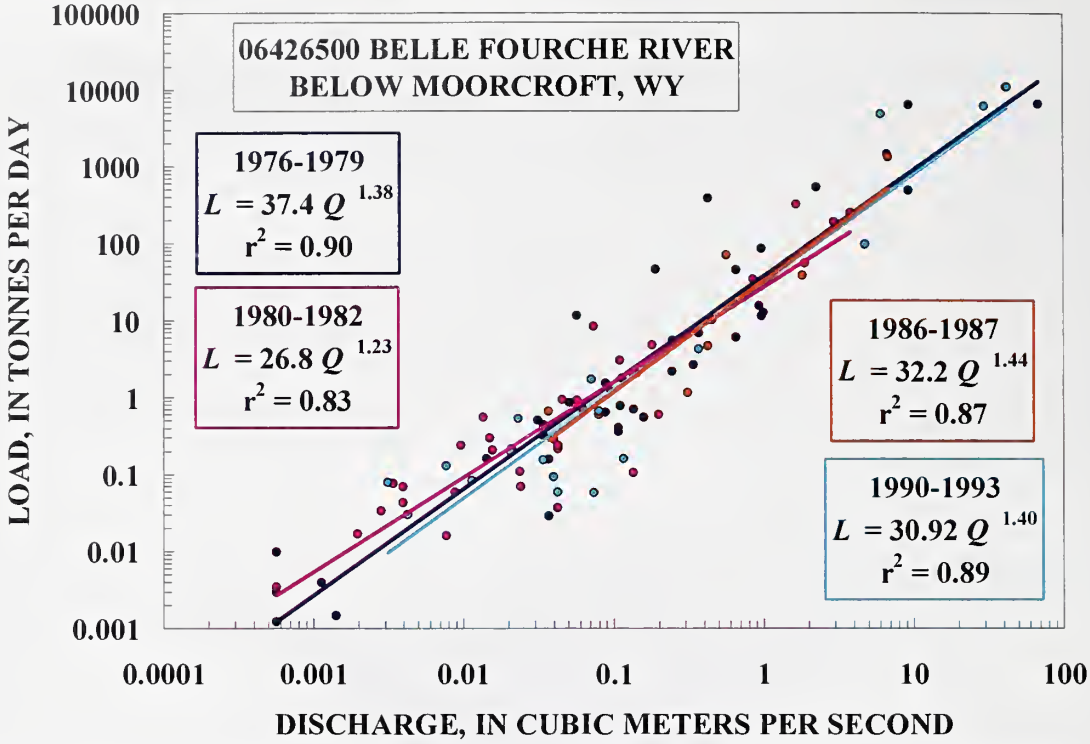

Figure 18 – Little change with time in the suspended-sediment transport relations derived for the Belle Fourche River below Moorcroft suggests a stable channel.

4.2.6 Bed-Material Conditions

As part of each RGA, bed material was characterized. If the bed material was dominated by gravels (2.00 mm or greater) or coarser fractions, a particle count was carried out. For particle counts, the intermediate axis of one hundred particles were measured. These were distributed according to the percentage of pools, riffles and runs in the reach to obtain a representative sample. Having carried out the particle count, if 16 % of the particles measured, had a median diameter of less than 2 mm, a bulk particle size sample of 100 g or greater was collected from the left, middle and right portions across the channel. This bulk sample was sieved to half-Phi intervals. Particle size data were combined directly with particle count data to give percentiles of class sizes and values for commonly used metrics such as the median particle size. If fines dominated the bed material, only a bulk sample was taken.

When concerned with water quality issues and their impact upon aquatic biota, the condition of the bed material may be a key factor. One critical bed condition for biota is the filling of interstitial spaces between coarse particles (material 2 mm or larger; gravel, cobbles and boulders) with fines (material smaller than 2 mm; sand, silt and clay). This 'filling of spaces' may reduce the habitat and breeding ground of macro-invertebrates. One way to examine this condition is through the "embeddedness" of the bed material. For this study embeddedness is defined as the percentage of material finer than 2 mm in an otherwise coarse matrix.

Analysis of bed material and embeddedness data was conducted in a similar way as the suspenbded-sediment transport data. That is, by separating the data from each ecoregion into stable and unstable sites and evaluating the data distributions. This is discussed in further detail in the results section.

4.3 Functional Traits Ecological Analysis

4.3.1 Study Sites

Ecological analyses were conducted for the Northwestern Great Plains Ecoregion (Ecoregion 43), in an attempt to develop functional links between fish populations and sediment transport and channel-stability metrics. This ecoregion was selected because it contained the greatest number of locations with available flow, suspended-sediment, and fish data from existing federal and state agencies databases. Figure 19 shows the co-located sites for USGS sediment and fish data collections within Ecoregion 43.

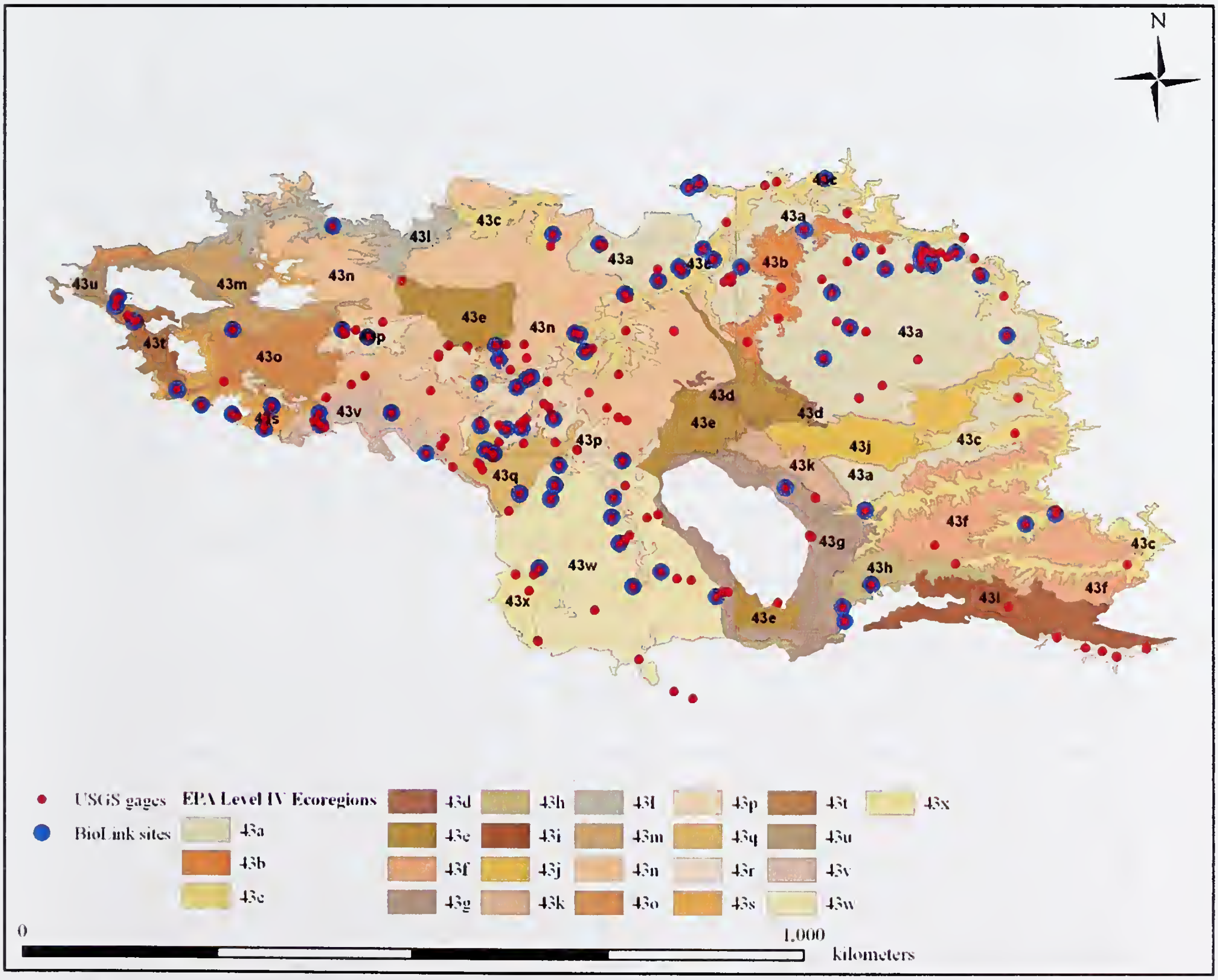

Figure 19 – Location map of functional traits ecological analysis study sites in the Northwestern Great Plains Ecoregion (43) showing USGS gauging stations with suspended-sediment data and fish data sites.

The following tasks were conducted to develop the necessary datasets for ecological analysis:

1. United States Geological Survey (USGS) gauging sites with flow and suspended sediment data were identified and compiled. These data included site information (gauge number, location latitude/longitude, period of record, drainage area, elevation). Suspended sediment metrics were computed as described in Section 4.1.
2. Channels near the USGS gauging sites were classified as morphologically stable or unstable by use of a field-based rapid geomorphic assessment (RGA); (Section 4.2).
3. Fish data from federal and state surveys were co-located at USGS gauging sites, and species presence/absence data were compiled (Section 4.3.2).
4. A matrix of fish species by functional traits was created in binary format using existing published literature, and only for those species compiled for this study's database (Section 4.3.3).
5. The matrix of fish species by functional traits and the fish presence/absence data at each site were used to enumerate functional traits composition at each site, forming a new data matrix of site x fish functional traits (Section 4.3.3).
6. Statistical analysis was conducted utilizing the site x sediment metric data matrix, the site x functional trait data matrix, and the site channel stability classification (Section 4.3.4).

Two basic approaches of ecological analysis were used: 1) relationships between sediment metrics and functional traits independent of the channel stability classification, and 2) testing whether differences in functional traits exist between channel stability classes. In the first approach, correlations between sediment metrics and functional traits were examined to identify thresholds that could represent a change in ecological condition (Table 6). The second approach identified what functional traits differed between stable and unstable channels, in which the analysis was dependent on the stability classification and not the sediment metrics.

Supporting these analyses, composition of functional traits found within the database was described to put results into context. As each ecoregion is unique in traits composition, understanding it provides some information on the relative importance of sediment-stressor gradients versus natural-environmental gradients. In the Northwestern Great Plains Ecoregion, natural environmental gradients of drainage area and elevation strongly influence fish community structure (Rahel and Hubert 1991; Lohr and Fausch 1997; Kral and Berry 2005; Hoagstrom *et al.* 2006; Fischer and Paukert 2008). The strength of the drainage area- and elevation-environmental gradients with respect to functional trait composition was examined in both approaches. In the second approach a channel-stability gradient, as a surrogate for a sediment stressor, was compared to these two environmental gradients. The purpose of this analysis was to provide evidence that the suspended-sediment stressor has the potential to influence changes in fish community structure, of equal or greater dominance of these strong natural gradients. Methods for database development and ecological analysis are detailed below.

Table 6 - Summary of fish functional traits and relationships to excessive suspended-sediment as an environmental stressor. Plotting codes for functional traits are shown in parentheses.

Functional Traits	Potential Stress from Excessive Suspended Sediment
Rearing Habitat Preferences - Open water, rivers, deep areas pools (HABDW) - Open water, rivers, shallow areas, backwaters (HABSW) - Pool, small rivers and streams, relatively deep, slow waters (HABPOOL) - Riffle, small rivers and stream, shallow, fast waters (HABRIF)	Excessive suspended sediment can cause sedimentation in river and stream pools, and river backwater areas reducing the quality of this habitat type. It may be a surrogate for channel instability, such that channel incision eliminates stream riffle habitat.
Feeding Trophic Guild - Generalist Feeder: consumes more than 3 different live food items (TRGEN) - Herbivore: consumes plant materials including algae and macrophytes (TRHERB) - Omnivore: consumes detritus, plant material, insects (TROMN) - Insectivore: consumes insects (TRINSE) - Piscivore: consumes fish (TRPISC)	Generalist feeders, herbivores, and omnivores should be less susceptible to prolonged and more frequent periods of suspended sediment and turbid waters because sight is not critical to obtaining food items. In contrast, insectivores and piscivores generally require some ability to see and capture their prey.
Feeding Location Guild - Bottom: benthic feeder on river/stream bottom (FEEDB) - Pelagic: open water and stream mid column feeder (FEEDP) - Surface: open water and stream surface feeder (FEEDS)	Bottom feeders can graze and sort through fine bed substrates to obtain their food items, and would typically be herbivores and omnivores, and may not need clear water to effectively to feed. Although some benthic insectivores may need clear water to feed. Pelagic feeders would predominately use sight to obtain prey, therefore would be most impacted by turbid waters. Turbid waters would minimally impact surface feeders.
Spawning Behavior (Reproductive) Guild - Non-guarder, open substratum spawner, non adhesive eggs (SPNGOW) - Non-guarder, open substratum spawner, adhere eggs to rocks or plants (SPNGOA) - Non-guarder, brood hiders, builds nests or redds (SPNGNS) - Guarder, no nest, adhere eggs on substrate (SPGADH) - Guarder, no nest, hides eggs in rock/bed substrate crevices/holes (SPGHO) - Guarder, nest builder, no specialized material (SPGNE) - Guarder, nest builder, use clean gravel/pebble (SPGNGR) - Guarder, nest builder, use soft mud and/or vegetation (SPGNMD)	Excessive suspended sediment will affect fish recruitment depending on spawning behavioral traits. Fish that do not guard their eggs, and disperse them into open waters will benefit from prolonged periods of turbid waters because eggs would be less likely to become food items. In contrast, fish that guard their eggs must be able to see and fend off predators. Fish that hide eggs in rock/bed substrate cavities and nest builders using clean gravels would be impacted if fine sediment smothered cavities and unstable channels depleted available gravel material for nests. Nest builders using soft mud may be minimally impacted by excessive suspended sediment.

4.3.2 Fish Data Compilation

Fish data sources obtained from federal and state agencies included:

1) USEPA Region 8 EMAP and REMAP datasets
2) North Dakota Division of Health (NDDH)
3) USGS Cooperative Fish & Wildlife Research Unit at South Dakota State University
4) Montana Department of Fish, Wildlife and Parks, online Fisheries Information System database (http://maps2.nris.state.mt.us/scripts/esrimap.dll?name=MFISH&Cmd=Main&Pc) accessed March 2, 2008.

Collection locations of fish data were co-located with USGS sites using latitude and longitude coordinates. A total of 58 sites were co-located with fish and USGS sediment data, in which the channel-stability condition during the period of record for sediment collection matched the present condition (Appendix D).

Fish species presence and absence data were compiled for each site from the above data sources. The majority of the fish data was collected between 2000 and 2003, although the full range of data included collections between 1997 and 2006. Some sites had multiple collections, and a species only had to be present once to be counted. In this study it is assumed that suspended-sediment transport metrics generally characterize the watershed condition at the time the fish collections were conducted. Utilizing fish presence and absence data reduces variability associated with biological sampling (i.e., gear, effort, and seasons). A summary list of 41 fish species found among the 58 sites is provided in Table 7.

4.3.3 Development of Functional Traits Matrices

A functional traits matrix was developed for the 41 fish species which included four major trait groups: preferred rearing habitat, feeding trophic guild, preferred feeding location, and spawning behavior (Table 7, Appendix F). These traits were selected because it was presumed that excessive suspended-sediment transport could impact the ability for a fish to express these traits, or biological needs (Table 6). Species trait information was readily available in the literature, and all source material was referenced in Table 7. The matrix consisting of fish species by row and trait attribute by column represents a binary cross-referenced database, where a value of "1" is given when a trait is expressed by a particular species, and a value of "0" when not. Traits codes for plotting are in Table 6.

Preferred rearing habitat traits consisted of deep open water, shallow open water, pools, and riffles. Matrix enumeration of rearing habitat trait expression required interpretation from species ecological descriptions. Data was compiled based on ecologic descriptions primarily from Holton (2003) and Smith (1979), and secondarily from Etnier and Starnes (2001) and Welker and Scarnecchia (2004). Ecological information for the Plains Killifish came from Rahel and Thel (2004). Depending on the species, more than one attribute could be expressed.

Table 7 – Fish species presence at study sites ordered by the number of sites species were present. Reference sources for development of the functional traits matrix were identified by: 1) Corker, *et al.* 2001; 2) Smith, 1979; 3) Holton, 2003; 4) Etnier and Starnes, 2001; and 5) Rahel and Thel, 2004.

Fish Name	Species	Species Code	Trait Reference Source	Numbers of sites species present
White Sucker	*Catostomus commersoni*	WHTSKR	1, 2, 3	43
Common Carp	*Cyprinus carpio*	CMCARP	1, 2, 3	35
Sand Shiner	*Notropis ludibundus*	SNDSHR	1, 2, 3	32
Flathead Chub	*Platygobio gracilis*	FLCHUB	1, 2, 3	30
Fathead Minnow	*Pimephales promelas*	FATHMW	1, 2, 3	30
Channel Catfish	*Ictlaurus punctatus*	CHCATF	1, 2, 3	28
Green Sunfish	*Lepomis cyanellus*	GRSUNF	1, 2, 3	26
Shorthead Redhorse	*Moxostoma macrolepidotum*	SREDHR	1, 2, 3	25
Longnose Dace	*Rhinichtys cataractae*	LGNSDC	1, 2, 3	24
Stonecat	*Notorus flavus*	STNCAT	1, 2, 3	23
River Carpsucker	*Carpiodes carpio*	RCARPS	2, 3	20
Northern Pike	*Esox lucius*	NOPIKE	1, 2, 3	17
Western Silvery Minnow	*Hybognathus argyritis*	WSILVY	1, 2, 3	15
Black Bullhead	*Ameiurus melas*	BKBULL	1, 2, 3	14
Goldeye	*Hiodon alsoides*	GOLDEY	1, 2, 3	14
Plains Minnow	*Hybognathus placitus*	PLNSMW	2, 3	13
Creek Chub	*Semotilis atromaculatus*	CKCHUB	1, 2, 3	12
Emerald Shiner	*Notropis atherinoides*	EMRSHR	1, 2, 3	9
Largemouth Bass	*Micropterus salmoides*	LMBASS	1, 2, 3	9
Smallmouth Bass	*Micropterus dolomieui*	SMBASS	1, 2, 3	9
Plains Killifish	*Fundulus zebrinus*	PLKILL	3, 5	8
Longnose Sucker	*Catostomus catostomus*	LNNSKR	1, 2, 3	7
Mountain Sucker	*Catostomus platyrhynchus*	MTNSKR	1, 2, 3	7
Blacknose Dace	*Rhinichtys atratulus*	BLNSDC	1, 2, 3	7
Brassy Minnow	*Hybognathus hankinsoni*	BRSSMW	1, 2, 3	6
Iowa Darter	*Etheostoma exile*	IOWADR	1, 2,3	6
Lake Chub	*Coesius plumbeus*	LKCHUB	1, 2, 3	6
Yellow Bullhead	*Ameiurus natalis*	YLBULL	1, 2, 3	6
Sauger	*Stizostedion canadense*	SAUGER	1, 2,3	5
Black Crappie	*Pomoxis nigromaculatus*	BLCRAP	1, 2, 3	5
Pumpkinseed	*Lepomis gibbosus*	PKSEED	1, 2, 3	5
Red Shiner	*Cyprinella lutrensis*	REDSHR	2, 4	5
Walleye	*Stizostedion vitreum*	WALLEY	1, 2, 3	5
Brown Trout	*Salmo trutta*	BROWNT	1, 2, 3, 4	4
Johnny Darter	*Etheostoma nigrum*	JOHNDR	1, 2, 4	4
Sturgeon Chub	*Macrhybopsis gelida*	STCHUB	2, 3	4
Rock Bass	*Ambloplites rupestris*	ROCKBS	1, 2, 3	4
Bigmouth Shiner	*Notropis dorsalis*	BGMSHR	1, 2, 4	3
Golden Shiner	*Notemigonus crysoleucas*	GLDSHR	1, 2, 3	3
Mountain Whitefish	*Prosopium williamsoni*	MTNWTF	1, 3	3
Brook Stickleback	*Culaea inconstans*	BKSTKB	1, 3	3

Feeding trophic traits consisted of generalist feeder, herbivore, omnivore, insectivore, and piscivore. Expression of feeding trophic traits was obtained directly from Barbour *et al.* (1999). If Barbour *et al* (1999) lacked an entry, Holton (2003) and Smith (1979) were used, requiring some interpretation of species ecological descriptions. A generalist feeder was determined when a species diet included more than three of the following items phytoplankton, macrophytes and filamentous algae, crustaceans, annelids, mollusks, insects, and fish, as listed in Coker *et al.* (2001). Fish species not in Coker *et al.* (2001), Holton (2003), Smith (1979), and Etnier and Starnes (2001) were consulted. Feeding location traits consisted of bottom, pelagic, and surface. They were directly obtained from Coker *et al.* (2001), unless not listed in that document than Holton (2003), Smith (1979), and Etnier and Starnes (2001) were consulted.

Spawning behavior traits consisted of: 1) non-guard, open water dispersal of non adhesive eggs, 2) non-guard, open water dispersal of adhesive eggs, 3) non-guard, builds nests (redds) for eggs, 4) guard after deposit adhesive eggs on bed or vegetation, 5) guard eggs after deposition in holes or crevices, 6) guard eggs in built nest of no special material, 7) guard eggs in built nests made of clean gravel/rock, and 8) guard eggs in built nest of soft mud and vegetation. They were directly obtained from Coker *et al.* (2001), unless not listed in that document; then Holton (2003), Smith (1979), and Etnier and Starnes (2001) were consulted. A separate summary list was created by simply delineating species as egg guarders or non-guarders.

Characterizing the functional-traits composition per site, a matrix was created consisting of sites in rows and the number of trait occurrences in columns (Appendix G). This operation required merging data from the functional traits matrix and the fish presence/absence database. If a fish species was present at a site its traits were counted, and the number of occurrences were summed per site and trait. Per site, trait occurrence data were normalized by species richness. Species richness per site is summarized in Appendix G.

4.3.4 Statistical Analysis

<u>Fish Functional Traits Composition</u>

The composition of functional traits within the species pool compiled for this study was accessed using two-way cluster analysis and dominance curve. PC-ORD 5.0 was used to perform these analyses using the species by functional traits matrix (McCune and Mefford 1999; McCune and Grace 2002). The two-way cluster analysis summarized graphically the trait expression per fish species as presence (expressed), and absence (not expressed). Classification used a relative Euclidean distance measure, Ward's group linkage method, and hierarchical agglomerative clustering of traits was normalized by trait maximum. A dominance curve for traits examined the trait dominance based only on the species pool within the dataset. Trait coordinates were plotted by log $\sum$ trait expression (y) versus their numerical rank by total species expressions (x). Statistical analysis also included descriptive statistics of functional traits composition based on the site data compilation rather than the species pool. Pie charts were developed per trait

group based on trait occurrence summaries for all 58 sites, and plotted as a percentage by trait group. Trait groups included: preferred rearing habitat, feeding trophic guild, feeding location, and spawning behavior.

Correlations among Fish Functional Traits and Suspended-Sediment Metrics

Relations among fish-functional traits and sediment metrics were examined using a Pearson correlation analysis, conducted with SPSS Statistics 17.0. Pearson correlations used the log transformed site data for frequency, duration and dosage of suspended-sediment concentration (Appendix E), mean, annual suspended-sediment yield (Appendix D), and number of trait occurrences per site species-richness (Appendix G). Relations among functional traits and the environmental gradients drainage area and elevation, were also examined using a Pearson correlation analysis. Statistical results were interpreted with a goal to find possible sediment-metric thresholds for impairment per functional traits. For identified thresholds, descriptive statistics (mean and standard deviation of 58 sites) were completed for the specific suspended-sediment frequency, duration, and dosage.

Differences in Fish Functional Traits Based on Channel Stability Classification

Differences in fish functional traits between stable and unstable channels were tested using independent-sample t-tests, conducted with SPSS Statistics 17.0. Functional traits data per site consisted of number of trait occurrences per site species-richness (Appendix G). Additional analysis included canonical correspondence analysis (CCA) per trait group using PC-ORD 5.0 (McCune and Mefford, 1999; McCune and Grace, 2002). This analysis was conducted to evaluate whether the stability gradient was dominant or of equal dominance to the drainage area and elevation environmental gradients. In this analysis, all traits were used as attributes in the main ordination matrix (site x traits), and stability, drainage area, and elevation attributes were used in the second matrix (site x 3 environmental factors).

5. RESULTS AND DISCUSSION

Using the procedures for developing suspended-sediment transport relations and the $Q_{1.5}$ discharge, values of both mean annual suspended-sediment yield and yield at the $Q_{1.5}$ were obtained for each site with fifteen or more suspended-sediment samples. Suspended-sediment transport data are reported in terms of yields (tonnes/year/km^2 for mean annual yields; and tonnes/day/km^2 for the $Q_{1.5}$), to enable comparison of streams of varying size within ecoregions. Because data for individual ecoregions were often non-normally distributed, quartile measures were used to describe data ranges and central tendencies.

It is important to keep in mind that the "reference" approach as defined in geomorphic terms and adopted in this and previous studies (Simon *et al.*, 2004a; Simon and Klimetz 2008a; 2008b) implicitly accounts for "natural" variability in sediment-transport rates between and within ecoregions. Data analysis proceeds initially at the broad, Level III scale to determine "reference" sediment-transport rates. Acknowledging the natural variability within ecoregions, "reference" sediment-transport rates were also determined by Level IV ecoregion or drainage basin where there was a sufficient number of sites.

Fish species presence and absence data compiled for 77 sites collocated near USGS gauging stations in Ecoregion 43 were used in statistical ordinations summarizing relationships with channel stability, suspended sediment transport, and basin physiographic variables. Physiographic variables that strongly influence fish watershed distribution were basin drainage area and site elevation above MSL. Autecological attributes were summarized for each fish species, and used in an analysis to examine differences in ecological function between stable and unstable sites, as determined by RGA field surveys. Statistically significant differences were found, and provide evidence of loss of ecological function from sedimentation. These findings are based on a "strength of evidence" approach recommended by the USEPA.

5.1 Relative Channel Stability

The majority of RGAs for the selected Level III Ecoregions were carried out between 2006 and 2007, providing current channel-stability conditions. Some parts of Ecoregions 15 and 17 were visited in 2001, however this is still considered 'recent' and used contemporaneously with the data collected in 2006 and 2007. RGA findings are given in Appendix C. In most cases it was appropriate to apply 'current' channel stability conditions to a given site, however suspended-sediment was sampled as early as 1949 at some sites, at which time channel stability may have been different. In situations where it was felt that channel stability at the time of suspended-sediment sampling was different to stability at the time of RGA fieldwork, channel stability was determined using other means, as described in Section 4.2.5.

The distribution of channel-stability conditions coinciding with the period of suspended-sediment sampling within each ecoregion is provided in Figure 20, with specific stages of channel evolution given in Table 8. It is not appropriate to use these values as a basis for channel stability across a given ecoregion, as the sites that these values represent are not evenly distributed spatially across each ecoregion. It is, however, appropriate to deduce that at the time of suspended-sediment sampling, the majority of sites where a sufficient number of suspended-sediment samples and associated instantaneous discharges were collected in Ecoregion 48 were geomorphically unstable. Almost half of the sites visited in Ecoregion 48 were stage V channels, in which aggradation and widening are the dominant geomorphic processes. Of the sites visited in Ecoregion 48, therefore, channels appear to be 'recovering' from disturbance.

In contrast to Ecoregion 48 with its predominantly unstable sites, the majority of sites visited in Ecoregions 15 and 17 were found to be relatively stable. Approximately half of the stable channels in Ecoregion 17 were pre-modified channels, typical of such a mountainous region. Surprisingly, pre-modified channels account for very few of the stable channels visited in Ecoregion 15, also a mountainous region. It is however important to consider that these values represent only channels with USGS gages where a sufficient number of suspended-sediment samples were collected and in Ecoregion 15 this includes some large rivers, where a stage VI channel is more likely to be found; the Clark Fork River, the Columbia River, the Kootenai River and the Flathead River for example.

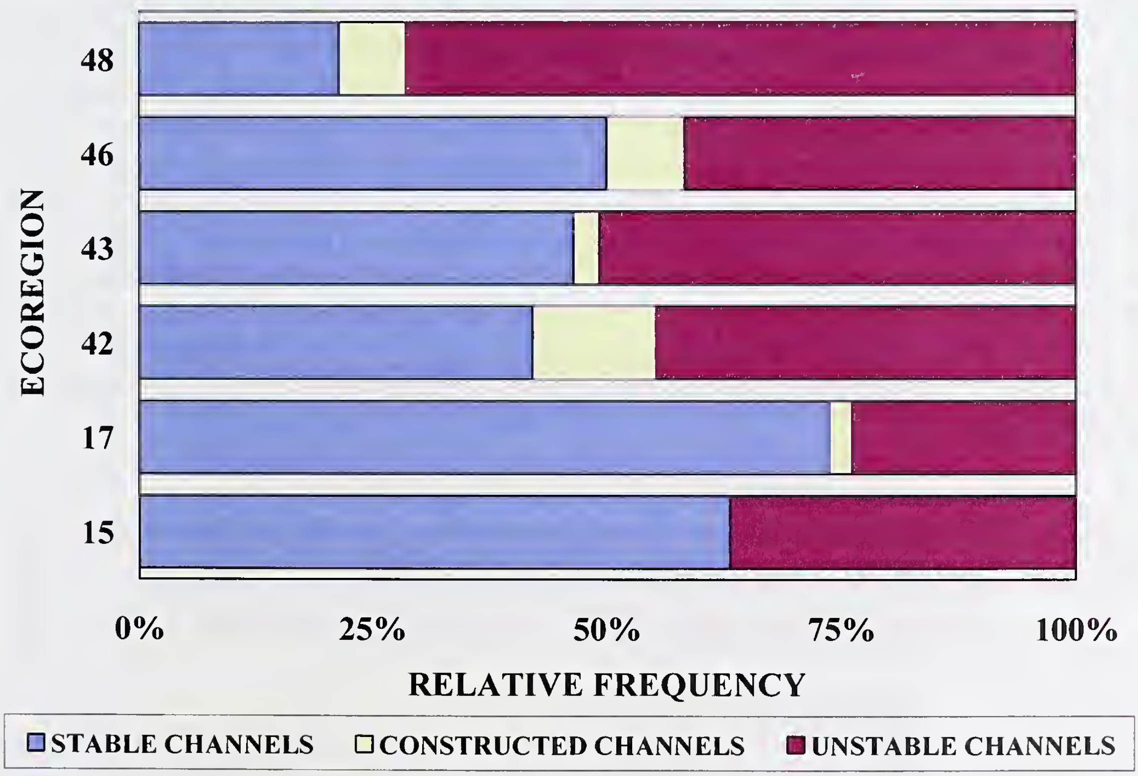

Figure 20 – Relative frequency of channel stability by Level III Ecoregion. Note: stable channels are stages I and VI; constructed channels are stage II, unstable channels are stages III, IV, and V.

Table 8 – Relative channel stability at time of suspended-sediment sampling for Level III Ecoregions.

Relative channel stability		Relative frequency (in percent) of channel stability at time of suspended-sediment sampling					
		15	**17**	**42**	**43**	**46**	**48**
I	Pre-modified	5.3	35.7	13.2	20.2	16.7	5.6
II	Constructed	0.0	2.4	13.2	2.7	8.3	5.6
III	Degradation	0.0	2.4	2.6	4.9	0.0	5.6
IV	Threshold	5.3	0.0	0.0	10.9	0.0	16.7
V	Aggradation	31.6	21.4	42.1	35.0	41.7	44.4
VI	Re-stabilization	57.9	38.1	29.0	26.2	33.3	22.2
STABLE (Stages I and VI)		**63.2**	**73.8**	42.1	46.4	50.0	27.8
UNSTABLE (Stages III, IV and V)		36.8	23.8	44.7	50.8	41.7	**66.7**
CONSTRUCTED (Stage II)		0.0	2.4	13.2	2.7	8.3	5.6
Number of sites in Ecoregion		19	42	38	183	36	14

Ecoregions 42, 43 and 46 appear to have no strong tendencies in channel stability, with similar frequencies of stable and unstable channels in each ecoregion. More than 60% of all channels visited in these three ecoregions were stages V or VI, recovering from system disturbance through aggradation. This may be a function of historical changes in land-use from open grassland prairie to agriculture, an important consideration both in terms of increased sediment delivery from floodplains and uplands to channels, channel instabilities resulting from channelization, and reductions in flow rates in streams due to increased irrigation. It may also be a result of high number of 'controlled' systems (such as dams) in these ecoregions (Table 9). In addition, these three ecoregions cover a huge area, between them includes parts of Montana, North and South Dakota, Minnesota, Wyoming and Nebraska, and include channels with drainage basins from 2 km^2 to over 600 000 km^2. Only a small number of sites visited exhibited signs of channel degradation (stages III and IV), with most occurrences in Ecoregions 43 and 48.

Table 9 – Number of dams in 2007 within selected Level III Ecoregions of EPA Region 8; compiled from the National Inventory of Dams.

Ecoregion	Number of dams	Dams per 100 km^2
15	180	0.22
17	430	0.26
42	1351	0.77
43	4368	1.22
46	353	0.26
48	105	0.23

Another way to use physical data collected in the field as part of the RGA is to observe the channel stability index, the sum of the nine criteria from the RGA form. In contrast to the results given above for relative channel stability in terms of the Stage of Channel Evolution Model, channel stability indices are given at time of RGA for Level III Ecoregions in Table 10 and Figure 21, therefore not necessarily at time of suspended-sediment sampling. A range of stability index scores applies to each stage of channel evolution. A channel with a stage of channel evolution of V, for example, can have a channel stability index of between 12 and the mid-20s, therefore there are different degrees of instability. Generally a score below 10 represents a stable site, whilst one above 20 is extremely unstable.

Patterns in channel stability index scores tend to mirror relative channel stability findings. Channels within Ecoregions 15 and 17 scored low on the channel stability index, therefore are mostly stable channels (represented by yellow, toward the left of Figure 21), while Ecoregion 48 has the highest percentage of sites which scored over 20 (represented by red, toward the right of Figure 21), illustrating a high proportion of extremely unstable channels.

Table 10 – Channel stability Index at time of Rapid Geomorphic Assessment (RGA). Values less than 10 are considered stable channels, while those over 20 are extremely unstable. Values between 10 and 20 represent varying degrees of channel stability.

Channel stability index	Relative frequency of channel stability index at time of RGA for each Ecoregion (percent)					
	15	17	42	43	46	48
0 - 5	10.5	7.3	2.9	4.6	8.8	0.0
5.5 - 10	31.6	43.9	23.5	21.8	5.9	17.6
10.5 - 15	31.6	26.8	35.3	24.7	41.2	5.9
15.5 - 20	21.1	12.2	32.4	31.0	32.4	23.5
20.5 - 25	0.0	9.8	5.9	10.3	8.8	41.2
25.5 - 30	5.3	0.0	0.0	7.5	2.9	11.8

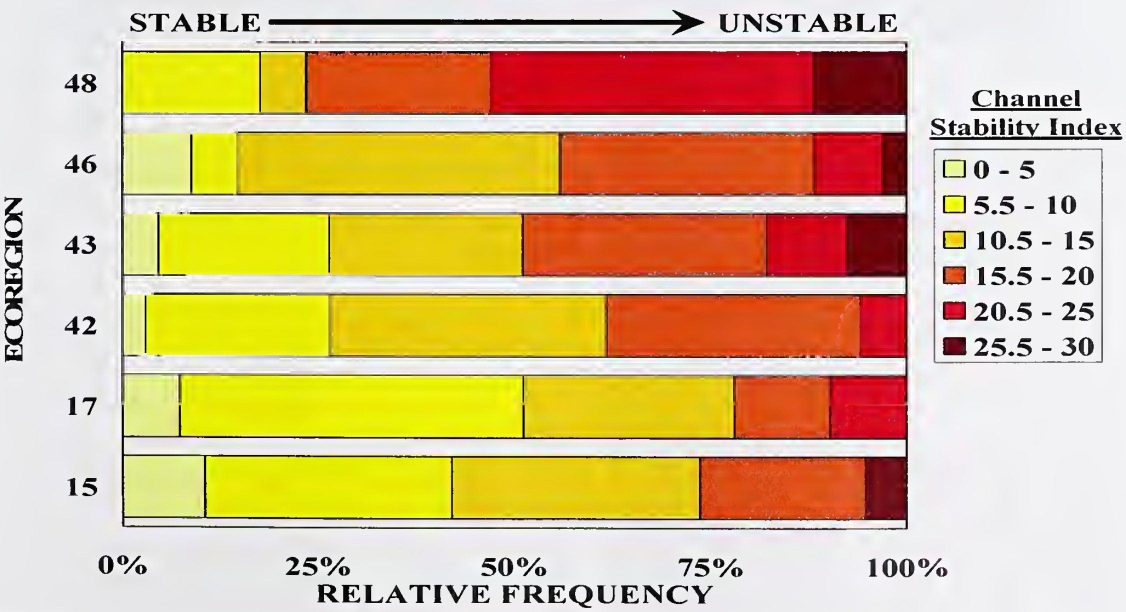

Figure 21 – Channel stability index scores are the sum of the nine RGA criteria. Low values (< 10) represent stable channels, high values (> 20) represent unstable channels.

5.2 Bed-Material Characteristics

As part of the RGA carried out at each site, bed material was sampled and a field estimate of dominant bed material obtained. Channels in mountainous regions (Ecoregions 15 and 17) were found to be dominated by gravel (2 – 65 mm median diameter) or boulder/cobble (greater than 65 mm median diameter) size particles; other ecoregions were dominated by sand (0.063 – 2 mm) bed channels (Table 11).

In cases where bed material was dominated by a coarse matrix, with a median particle diameter greater than 2 mm, embeddedness was calculated. For the purposes of this study, a metric for embeddedness is defined as the percentage of fine material (less than 2 mm median particle diameter) present in an otherwise coarse dominant bed material matrix (Kondolf *et al.*, 2003). Embeddedness values were separated by relative channel stability to provide a 'reference' embeddedness value for each Level III Ecoregion (Table 12). It is essential to note the number of sites that embeddedness values were calculated from in Table 12, as this will dictate the 'reliability' of the data. Embeddedness values are not provided for Ecoregion 48 as there were no stable channels with a dominant, coarse-dominated bed material, and just 2 unstable coarse dominated bed material channels. In some cases values should be used simply as a guide, such as those calculated from as few as three and four values; Ecoregions 42 and 44 'reference' values. Values of fine material within a coarse matrix were greater in unstable channels than for stable in Ecoregions 15, 17, 43 and 46. Similar amounts of fines were noted in both stable and unstable channels within Ecoregion 42; however these values are calculated from just 4 and 3 sites respectively.

Table 11 – Number of sites with a given dominant bed material for each Level III Ecoregion.

Median particle diameter in mm	Size class	Number of sites within each Level III Ecoregion with dominant bed material					
		15	17	42	43	46	48
> 65	Boulder/cobble*	6	20	5	19	2	0
2 - 65	Gravel	10	19	10	45	8	3
0.063 - 2	Sand	3	1	18	111	24	10
< 0.063	Silt/clay	0	0	0	0	1	0

* Includes bedrock dominated channel beds. In cases where water was too deep or swift, boulder/cobble dominated channels were not sampled.

Table 12 – Embeddedness values for by Level III Ecoregion, calculated as the percentage of fine material present in a coarse dominated bed material. Note the small number of observations for stable streams in all ecoregions except Ecoregions 17 and 43, for which 'reference' embeddedness values are highlighted in yellow.

COARSE DOMINATED STABLE CHANNELS										
	Ecoregion 15		Ecoregion 17		Ecoregion 42		Ecoregion 43		Ecoregion 46	
	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)
10th Percentile	0.60	97.2	0.0	93.0	1.3	75.7	5.5	56.2	1.4	82.8
25th Percentile	**1.0**	**98.0**	**1.0**	**96.0**	**1.8**	**86.8**	**8.3**	**84.3**	**3.4**	**90.6**
50th percentile	**2.0**	**98.0**	**2.0**	**98.0**	**4.5**	**95.5**	**11.3**	**88.7**	**4.8**	**95.2**
75th Percentile	**2.0**	**99.0**	**4.6**	**99.0**	**13.2**	**98.3**	**15.8**	**91.8**	**9.4**	**96.6**
90th Percentile	2.8	99.4	7.0	100.0	24.3	98.7	43.8	94.5	17.2	98.6
Mean	1.7	98.3	3.59	96.4	10.4	89.6	16.9	83.1	8.0	92.0
Number of sites	7	7	27	27	4	4	18	18	4	4

COARSE DOMINATED UNSTABLE CHANNELS										
	Ecoregion 15		Ecoregion 17		Ecoregion 42		Ecoregion 43		Ecoregion 46	
	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)	Fines (< 2 mm median diameter)	Coarse (> 2 mm median diameter)
10th Percentile	1.9	87.7	0.0	94.8	2.0	93.6	5.0	53.3	3.6	81.0
25th Percentile	**3.3**	**91.8**	**0.0**	**95.0**	**3.0**	**94.5**	**11.0**	**65.0**	**9.0**	**84.0**
50th percentile	**5.0**	**95.0**	**4.0**	**96.0**	**4.0**	**96.0**	**25.0**	**75.0**	**10.5**	**89.5**
75th Percentile	**8.3**	**96.8**	**5.0**	**100.0**	**5.5**	**97.0**	**35.0**	**89.0**	**16.0**	**91.0**
90th Percentile	12.3	98.1	5.2	100.0	6.4	97.6	46.7	95.0	19.0	96.4
Mean	6.5	93.5	2.89	97.1	4.3	95.7	25.4	74.6	11.3	88.7
Number of sites	4	4	9	9	3	3	25	25	5	5

'Reference' embeddedness values seem to group by region. The mountainous regions predictably have the lowest proportion of fine materials embedded within a coarse matrix, with a median 'reference' fines value of just 2 % in both Ecoregion 15 and 17. Adjacent Ecoregions 42 and 46 have a 'reference' embeddedness value of approximately 5 %; however both of these ecoregions have just 4 stable channels with a coarse dominated bed material from which to calculate embeddedness. Ecoregion 43 has the highest 'reference' embeddedness value (11%) within the ecoregions studied here. This value is generally less than 'reference' embeddedness values calculated for other ecoregions (Table 13). An embeddedness standard of 10% was determined by Hausle and Coble (1976) for Brook trout based on the percent of bed material finer than 2mm. Others, using 0.83 mm as the fine-sediment discriminator, found standards ranging from 7.5% to 21%, with an average of 13.7% (Kondolf *et al.*, 2003). Thus, values obtained in this report appear to be reasonable.

Table 13 – 'Reference' embeddedness values for ecoregions in EPA Region 8 compared to values from other locations based on the percent finer than 2 mm in a coarse-grained dominated bed material.

Ecoregion number and name	'Reference' embeddedness value	Source
15: Northern Rockies	2%	This study
17: Middle Rockies	2%	This study
22: Arizona/New Mexico Plateau	16%	Heins *et al.*, 2004
42: Northwestern Glaciated Plains	5%	This study
43: Northwestern Great Plains	11%	This study
46: Northern Glaciated Plains	5%	This study
65: Southeastern Plains	19%	Klimetz and Simon, 2006.
67: Ridge and Valley	4%	Simon *et al.*, 2004b
74: Mississippi Valley Loess Plains	22%	Klimetz and Simon, 2006.

5.3 Suspended-Sediment Yields at the 1.5-Year Recurrence Interval Discharge

'Reference' or 'target' values for suspended-sediment yield at the $Q_{1.5}$ (based on the median value) ranged over two orders of magnitude, from 0.0039 T/d/km^2 in Ecoregion 46 to 0.17 T/d/km^2 in Ecoregion 43 (Table 14). Median, suspended-sediment yields at the $Q_{1.5}$ for unstable sites were generally an order of magnitude greater than stable or 'reference' values for each of the Level III Ecoregions for which suspended-sediment transport was calculated (Figure 22). The results shown in Figure 22 are all plotted using the same scale on the ordinate, to make comparisons between ecoregions easier.

Table 14 - Suspended-sediment median yield (given in red) and quartile values (in bold) at the $Q_{1.5}$ for all, stable and unstable sites. Note the number of sites used to calculate percentile values.

ALL SITES	Suspended-sediment yield at $Q_{1.5}$ in T/d/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	0.00730	0.0261	0.00476	0.0228	0.00164	0.0261
25th Percentile	**0.0169**	**0.0838**	**0.0189**	**0.0986**	**0.00357**	**0.0529**
50th Percentile	**0.0563**	**0.136**	**0.0504**	**0.423**	**0.00831**	**0.0850**
75th Percentile	**0.3697**	**0.388**	**0.120**	**1.49**	**0.202**	**0.213**
90th Percentile	0.593	1.88	1.58	10.3	0.572	0.306
Number of sites	15	46	29	131	37	14

STABLE SITES	Suspended-sediment yield at $Q_{1.5}$ in T/d/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	0.00600	0.0197	0.00213	0.00677	0.00124	0.0254
25th Percentile	**0.00861**	**0.0617**	**0.00745**	**0.035**	**0.00233**	**0.0335**
50th Percentile	**0.0253**	**0.116**	**0.0217**	**0.170**	**0.00393**	**0.0602**
75th Percentile	**0.0525**	**0.189**	**0.0501**	**0.380**	**0.00831**	**0.0837**
90th Percentile	0.137	0.365	0.0914	0.693	0.131	0.0860
Number of sites	10	31	13	50	17	4

UNSTABLE SITES	Suspended-sediment yield at $Q_{1.5}$ in T/d/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	0.173	0.334	0.0504	0.146	0.00210	0.0607
25th Percentile	**0.267**	**0.704**	**0.0770**	**0.440**	**0.0142**	**0.0704**
50th Percentile	**0.370**	**1.16**	**0.245**	**1.24**	**0.0768**	**0.177**
75th Percentile	**0.443**	**3.13**	**1.80**	**4.33**	**0.304**	**0.288**
90th Percentile	0.483	4.15	2.35	21.0	0.664	0.334
Number of sites	4	9	11	60	14	9

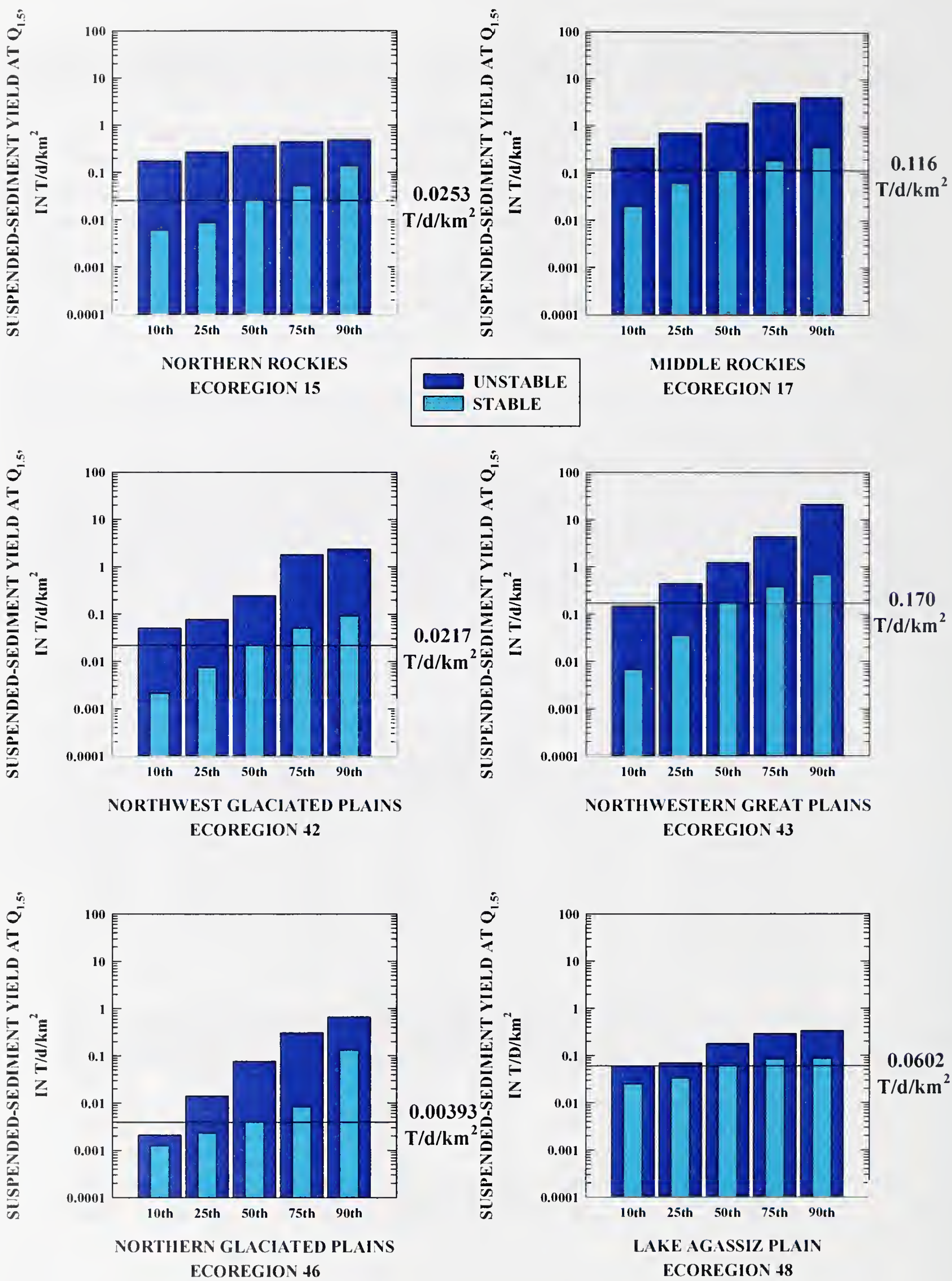

Figure 22 – Suspended-sediment yield values at the $Q_{1.5}$ for both stable (light blue) and unstable (dark blue) channels; 'reference' values (median value for stable channels) are given by horizontal lines.

Statistical tests were conducted to compare data distributions within each ecoregion to test for the validity of the overall approach of determining 'reference' transport rates at the $Q_{1.5}$ (and later as annual values) using geomorphically stable and unstable channels.. If the data distribution was determined to be normally distributed, a t-test of the means was carried out. For non-normally distributed data, the Mann-Whitney rank sum test was used to compare median values. For each of the ecoregions studied, it was found that 'reference' sediment yields at the $Q_{1.5}$ were significantly different (p-value < 0.05) than the sediment yields for the unstable channels within the same Level III Ecoregion (Table 15).

Table 15 – Tests of statistically significant differences between stable and unstable suspended-sediment yields at the $Q_{1.5}$ in the studied Ecoregions.

Level III Ecoregion	Statistically significant difference between stable and unstable yield values	Normally distributed	$Q_{1.5}$ suspended-sediment yields: Stable Observed median	Stable Number of data	Unstable Observed median	Unstable Number of data	p value
15	Yes	No	0.0253	10	0.37	4	0.028
17	Yes	No	0.116	31	1.16	9	< 0.001
42	Yes	No	0.0217	13	0.245	11	0.002
43	Yes	No	0.17	50	1.24	60	< 0.001
46	Yes	No	0.00393	17	0.0829	13	0.027
48	Yes	Yes	0.029	4	0.177	9	0.025

Owing to the substantial range of suspended-sediment yield values and the uncertainty inherent in regionalizing these data, it is more appropriate to consider ranges in 'reference' values as opposed to utilizing only the median value. In work with other cooperators and stakeholders based on previous studies, the inter-quartile range is used as the "target". These values are shown for each Level III Ecoregion in bold in Table 14, above. For example, the "target" range for Ecoregion 46 is from 0.00233 to 0.00831 $T/d/km^2$ at the $Q_{1.5}$. The variation in inter-quartile ranges for all of the ecoregions can be clearly seen in Figure 23. Ecoregion 43 has the largest inter-quartile range of 'reference' values, which may be related to variable hydrologic, topographic, and geologic conditions within the vast area encompassed by Ecoregion 43. Due to the greater availability of data in Ecoregion 43, suspended-sediment yield data in this ecoregion (the Northwestern Great Plains) will be investigated further using smaller spatial breakdowns (Level IV Ecoregions and sub-basins) in Section 5.6.

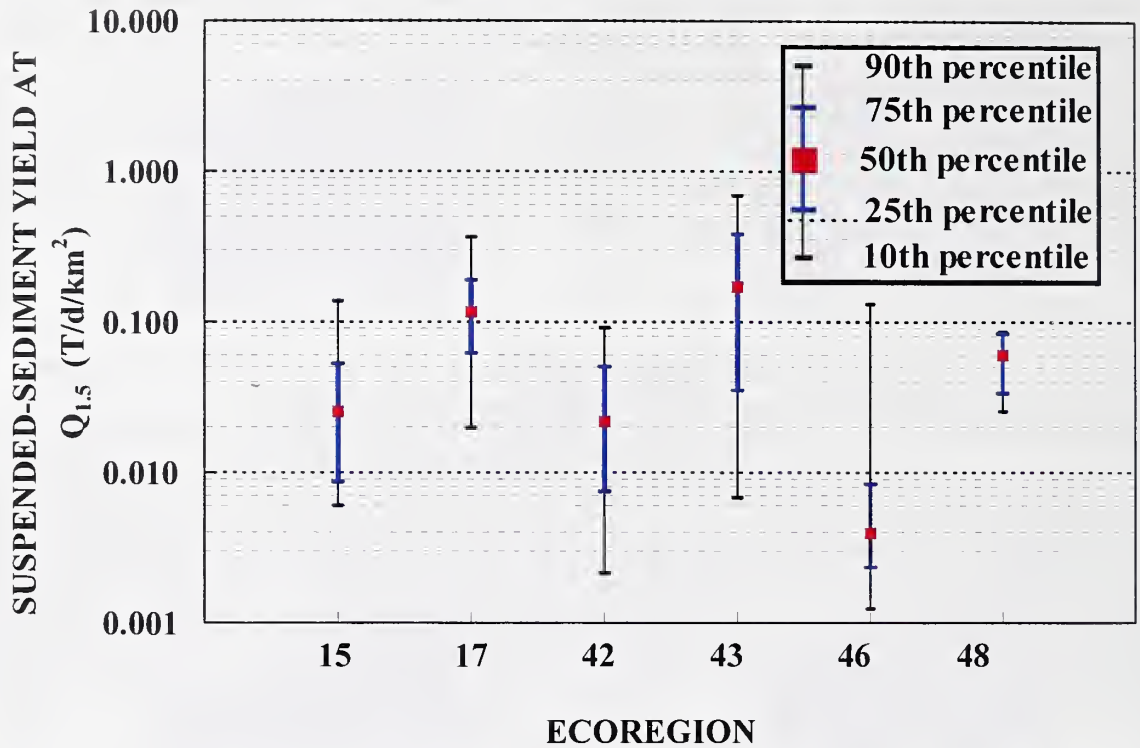

Figure 23 – Variations between ecoregions in 'reference' suspended-sediment yields and quartile values at the $Q_{1.5}$.

In comparison to ecoregions in other parts of the country, 'reference' suspended-sediment yield values at the $Q_{1.5}$ are relatively low. 'Reference' $Q_{1.5}$ suspended-sediment yield values for Ecoregions 15, 42, and 46 are lower than coastal-plain areas in the southeastern United States (Ecoregions 63 and 75: 0.0313 and 0.0379 T/d/km^2, respectively; Klimetz and Simon, 2006). While Ecoregions 17 and 43 have the highest $Q_{1.5}$ 'reference' yield values in the region, these values are still lower than all but coastal areas of EPA Region 4. Relatively high 'reference' $Q_{1.5}$ yield values in Ecoregion 17 may be the result of large sediment-transport events (including mass movements) that occur during extreme events combined with land use disturbances such as logging, mining and livestock grazing. Higher Ecoregion 43 $Q_{1.5}$ yields may be partly attributed to the highly erosive materials of the Badlands and the low vegetation growth rate caused by characteristically low rainfall. Low gradient channels throughout the flat to gently rolling landscape of the Northern Glaciated Plains, Ecoregion 46, are likely to be the major reason for such low transport rates. Even unstable channels in Ecoregion 46 transport especially low rates of suspended-sediment.

5.4 Mean Annual Suspended-Sediment Yields

Mean annual suspended-sediment yields vary by more than an order of magnitude across the studied ecoregions, ranging from 0.58 T/y/km^2 in Ecoregion 46 to 8.95 T/y/km^2 in Ecoregion 43 (Table 16). 'Reference' mean annual suspended-sediment yields show a similar range with stable streams in Ecoregion 46 producing 0.351 T/y/km^2 while stable streams produce 4.72 T/y/km^2 in Ecoregion 17 (Table 16, Figure 24). As with yields at the $Q_{1.5}$, median values for unstable streams were generally an order of magnitude greater than for stable or 'reference' values in most of the Level III Ecoregions. Exceptions to this were Ecoregions 42 and 48, however only three sites were used to create 'reference' values in Ecoregion 48. While there is some alteration in the ranking of Ecoregions by annual and $Q_{1.5}$ yield 'reference' values, similar groupings remain. Ecoregion 17 and 43 'reference' channels transport the largest amount of suspended-sediment annually and have the greatest inter-quartile ranges, implying more disparity between 'stable' channels in these ecoregions (Figure 25). Ecoregions 46 and 48 mean annual suspended-sediment yields are the lowest in the region with a much smaller inter-quartile range; in Ecoregion 48 this may be the number of sites used to calculate the distributions; however 13 'reference' sites were used in Ecoregion 46.

Table 16 – Mean annual suspended-sediment median yield (given in red) and quartile values (in bold) for all, stable and unstable sites.

ALL SITES

	Mean annual suspended-sediment yield in T/y/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	0.787	1.47	0.460	1.09	0.0748	1.20
25th Percentile	**1.35**	**3.35**	**1.032**	**2.84**	**0.210**	**1.96**
50th Percentile	**3.95**	**5.92**	**3.37**	**8.95**	**0.579**	**5.23**
75th Percentile	**11.4**	**24.6**	**7.13**	**37.6**	**5.18**	**8.81**
90th Percentile	14.2	39.3	44.8	167	7.86	15.0
Number of sites	14	42	26	124	27	13

STABLE SITES

	Mean annual suspended-sediment yield in T/y/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	0.630	1.22	0.286	0.759	0.0708	1.20
25th Percentile	**0.846**	**3.01**	**0.537**	**1.52**	**0.158**	**1.23**
50th Percentile	**2.10**	**4.72**	**1.03**	**3.07**	**0.351**	**1.28**
75th Percentile	**3.72**	**8.15**	**2.43**	**6.51**	**0.579**	**3.30**
90th Percentile	6.30	13.4	4.39	12.0	4.33	4.52
Number of sites	9	28	12	48	13	3

UNSTABLE SITES

	Mean annual suspended-sediment yield in T/y/km^2					
	15	**17**	**42**	**43**	**46**	**48**
10th Percentile	8.29	16.4	2.51	5.80	0.226	3.56
25th Percentile	**8.37**	**30.3**	**5.90**	**15.1**	**0.788**	**4.75**
50th Percentile	**10.4**	**32.5**	**7.83**	**31.3**	**5.19**	**8.16**
75th Percentile	**12.5**	**39.5**	**41.0**	**96.5**	**7.87**	**11.2**
90th Percentile	12.7	69.7	71.3	209	10.2	16.9
Number of sites	4	9	12	58	11	9

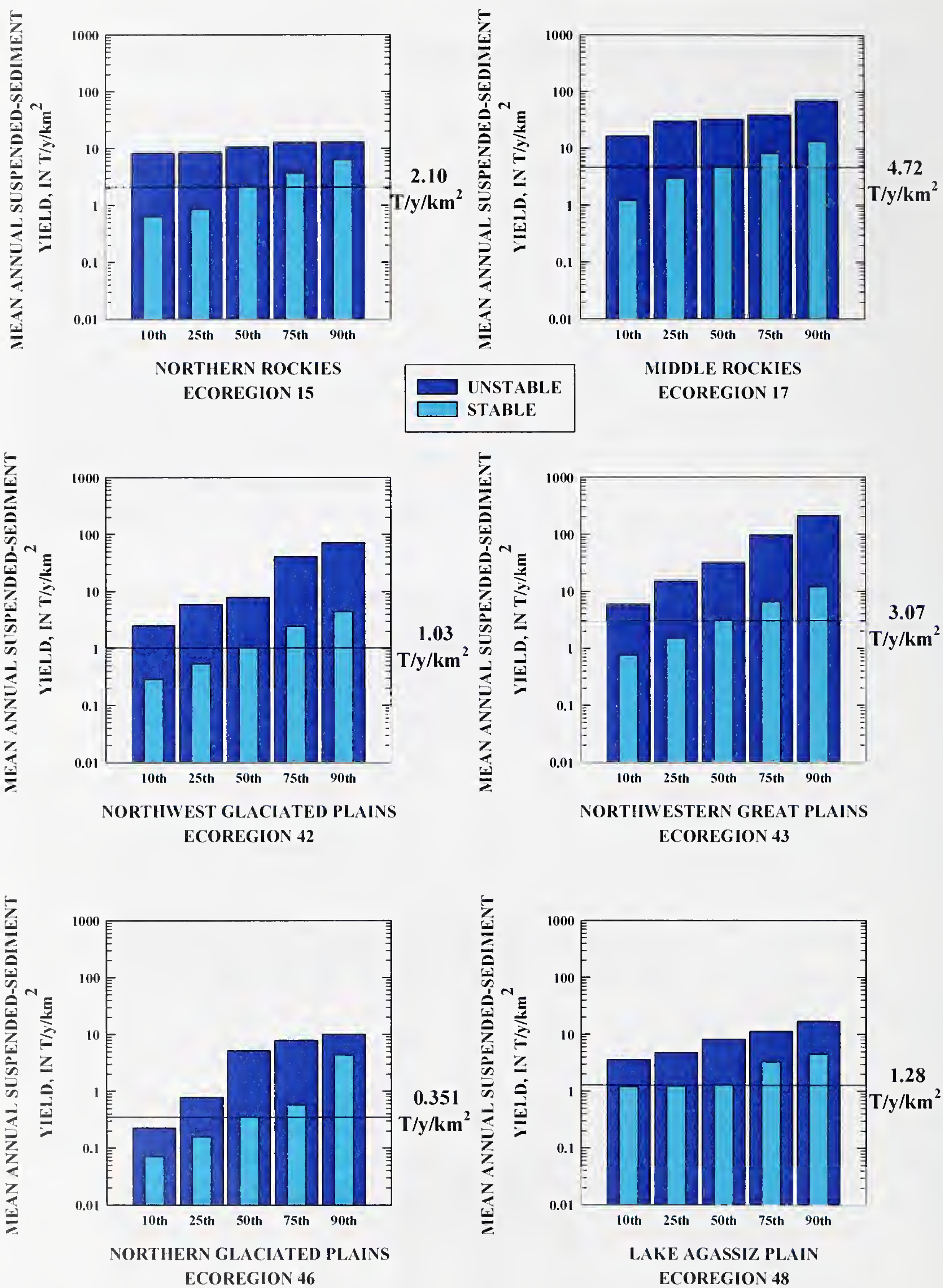

Figure 24 – 'Reference' mean annual suspended-sediment yield (horizontal line) and percentile values for both stable (light blue) and unstable (dark blue) channels.

To further test the validity of the approach of determining annual 'reference' transport rates by differentiating between geomorphically stable and unstable channels, statistical tests to compare data distributions within each ecoregion were conducted. For each of the ecoregions studied, it was again found that 'reference' sediment yields were significantly different (p-value < 0.05) than the sediment yields for the unstable channels within the same Level III Ecoregion (Table 17).

Table 17 – Tests of statistically significant differences between stable and unstable mean-annual suspended-sediment yields in the studied Ecoregions.

Level III Ecoregion	Statistically significant difference between stable and unstable yield values	Normally distributed	Mean annual suspended-sediment yields: Stable, Observed median	Stable, Number of data	Unstable, Observed median	Unstable, Number of data	p value
15	Yes	Yes	2.1	9	10.4	4	0.037
17	Yes	No	4.72	28	32.5	9	< 0.001
42	Yes	No	1.03	12	7.83	12	< 0.001
43	Yes	No	3.07	48	31.3	58	< 0.001
46	Yes	No	0.351	13	5.94	10	0.017
48	Yes	Yes	1.18	3	8.16	9	0.042

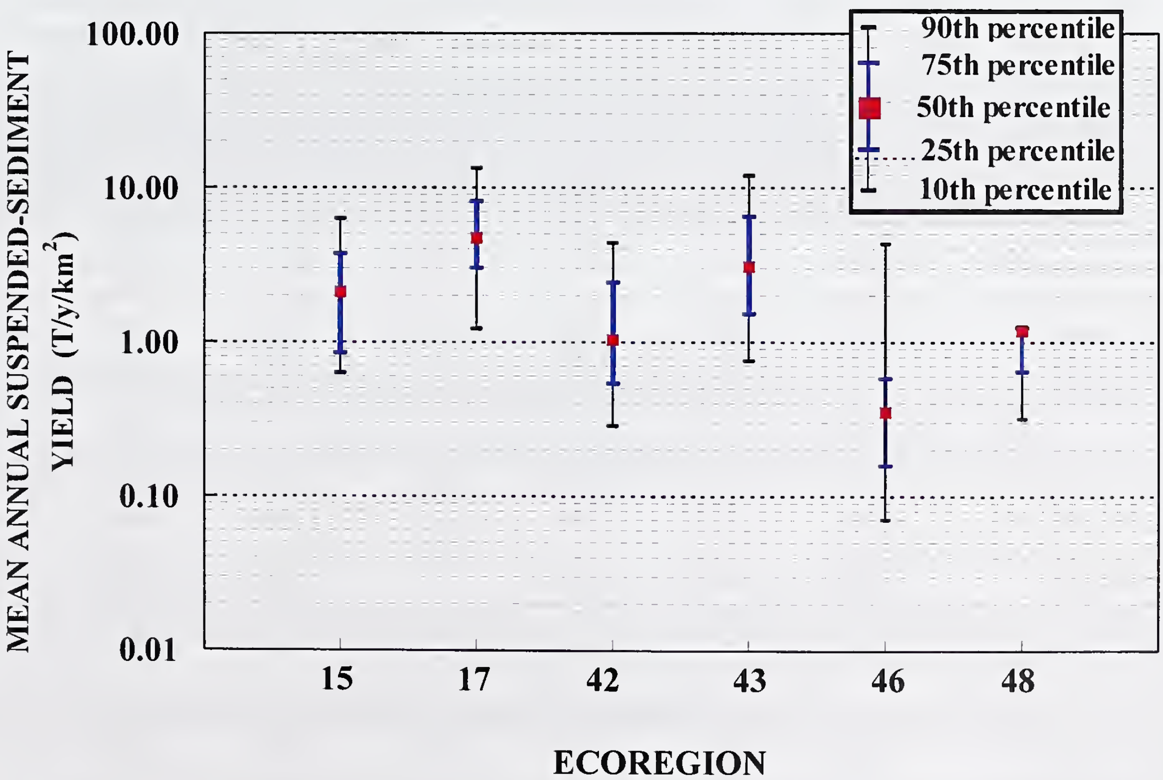

Figure 25 – Variations between ecoregions in mean annual 'reference' suspended-sediment yields and quartile values.

5.5 Suspended-Sediment Yields by Drainage Basin Size

To address concerns regarding the potential application of 'reference' sediment-yield values for large fluvial systems developed using data from a range of drainage basin sizes, an evaluation of data trends by basin size was conducted for Ecoregions 17, 43 and 46. By definition, suspended-sediment transport data expressed as yields accounts for differences in drainage area, as loads are divided by area to produce values in T/km^2. Still, there remains uncertainty as to whether values from basins of vastly different size can be compared because it is assumed that there is greater sediment storage (lower yields) in larger systems. To investigate this question, suspended-sediment yields were sorted into groups based on order-of-magnitude differences in watershed area (ie. 0 - 100, 101 – 1000 km^2 etc.).

For three of the Ecoregions, there were a sufficient number of sites, over a range of drainage basin size classes to make such comparisons. Mean annual and $Q_{1.5}$ suspended-sediment transport rates, sorted into drainage-area classes are given for all, stable and unstable sites for the Middle Rockies (Ecoregion 17), Northwestern Great Plains, (Ecoregion 43) and Northern Glaciated Plains (Ecoregion 46), in Tables 18, 19 and 20, respectively. As ecoregions are separated into the several drainage-area categories, the number of data available within each category decreases dramatically. It is, therefore, essential to note the "Number" of sites used to calculate the yield percentiles in each drainage area category.

Table 18 – Suspended-sediment transport rates for the Middle Rockies, Ecoregion 17, separated by drainage basin size class and relative channel stability. Note the small number of observations in some size classes.

	Mean annual yield in T/y/km^2 Drainage basin area in km^2 (less than)				Yield at the $Q_{1.5}$ in T/d/km^2 Drainage basin area in km^2 (less than)			
	100	**1000**	**10000**	**100000**	**100**	**1000**	**10000**	**100000**
ALL SITES								
10th Percentile		1.47	1.05	6.26	0.141	0.0434	0.0116	0.114
25th Percentile		**2.70**	**4.02**	**6.64**	**0.203**	**0.102**	**0.0474**	**0.127**
50th Percentile		**3.26**	**5.42**	**7.26**	**0.301**	**0.117**	**0.0967**	**0.149**
75th Percentile		**16.73**	**30.9**	**7.67**	**0.574**	**0.394**	**0.773**	**0.162**
90th Percentile		60.3	39.8	7.92	0.950	2.10	3.16	0.170
Number of sites	2	12	20	3	4	13	20	3
STABLE SITES								
10th Percentile		1.33	0.952	6.26		0.0394	0.0103	0.114
25th Percentile		**1.61**	**3.08**	**6.64**		**0.0773**	**0.0388**	**0.127**
50th Percentile		**2.72**	**4.49**	**7.26**		**0.116**	**0.0828**	**0.149**
75th Percentile		**3.19**	**5.65**	**7.67**		**0.143**	**0.108**	**0.162**
90th Percentile		3.26	8.64	7.92		0.260	0.200	0.170
Number of sites	1	6	15	3	2	7	15	3
UNSTABLE SITES								
10th Percentile		15.2	31.2			0.602	0.815	
25th Percentile		**24.3**	**32.4**			**1.21**	**0.981**	
50th Percentile		**39.5**	**32.5**			**2.25**	**1.16**	
75th Percentile		**83.5**	**38.1**			**4.62**	**3.13**	
90th Percentile		110	48.4			6.05	3.31	
Number of sites	0	3	5	0	0	3	5	0

Table 19 – Suspended-sediment transport rates for the Northwestern Great Plains, Ecoregion 43, separated by drainage basin size class and relative channel stability. Note the small number of observations in some size classes.

	Mean annual yield in T/y/km^2 Drainage basin area in km^2 (less than)				Yield at the $Q_{1.5}$ in T/d/km^2 Drainage basin area in km^2 (less than)			
ALL SITES	**100**	**1000**	**10000**	**100000**	**100**	**1000**	**10000**	**100000**
10th percentile	1.33	1.24	1.01	4.63	0.0339	0.0453	0.0148	0.0713
25th percentile	**1.72**	**2.17**	**2.90**	**13.5**	**0.139**	**0.119**	**0.085**	**0.165**
50th percentile	**2.39**	**6.28**	**9.69**	**38.8**	**0.328**	**0.296**	**0.536**	**1.44**
75th percentile	**5.32**	**9.06**	**31.6**	**150**	**0.610**	**0.494**	**1.49**	**5.05**
90th percentile	21.4	84.0	130	235	0.884	4.29	7.66	21.1
Number of sites	12	30	49	28	14	34	50	27
STABLE SITES								
10th percentile	1.26	1.21	0.23	11.1	0.169	0.0238	0.00262	0.261
25th percentile	**1.44**	**1.52**	**1.17**	**23.1**	**0.285**	**0.081**	**0.0146**	**0.635**
50th percentile	**1.74**	**2.82**	**3.00**	**43.2**	**0.479**	**0.225**	**0.0639**	**1.44**
75th percentile	**2.39**	**6.51**	**4.55**	**234**	**0.729**	**0.352**	**0.181**	**13.5**
90th percentile	2.77	8.1	7.0	528	0.880	0.43	0.334	68.9
Number of sites	3	20	20	5	3	22	20	5
UNSTABLE SITES								
10th percentile		5.03	7.18	10.30		0.258	0.510	0.120
25th percentile		**8.44**	**16.69**	**22.2**		**0.300**	**0.755**	**0.330**
50th percentile		**17.3**	**26.6**	**49.0**		**0.838**	**1.32**	**1.59**
75th percentile		**152**	**65.0**	**155**		**5.94**	**4.30**	**5.05**
90th percentile		208	212	198		29.4	24.1	21.0
Number of sites	1	8	24	19	1	8	26	19

Table 20 - Suspended-sediment transport rates for the Northern Glaciated Plains, Ecoregion 46, separated by drainage basin size class and relative channel stability. Note the small number of observations in some size classes.

	Mean annual yield in T/y/km^2 Drainage basin area in km^2 (less than)				Yield at the $Q_{1.5}$ in T/d/km^2 Drainage basin area in km^2 (less than)			
ALL SITES	**100**	**1000**	**10000**	**100000**	**100**	**1000**	**10000**	**100000**
10th Percentile		0.307	0.139	0.085	0.517	0.00637	0.00273	0.000829
25th Percentile		**0.659**	**0.213**	**0.189**	**0.618**	**0.0104**	**0.00359**	**0.00177**
50th Percentile		**3.05**	**0.579**	**0.461**	**0.786**	**0.0959**	**0.0394**	**0.00393**
75th Percentile		**5.95**	**7.84**	**1.32**	**0.9637**	**0.3796**	**0.1719**	**0.00767**
90th Percentile		32.1	8.35	2.72	1.07	1.81	0.232	0.0284
Number of sites	0	6	9	12	3	9	10	15
STABLE SITES								
10th Percentile		0.255	0.169	0.0728		0.00485	0.00213	0.000455
25th Percentile		**0.567**	**0.186**	**0.0787**		**0.00814**	**0.00269**	**0.00167**
50th Percentile		**0.934**	**0.213**	**0.206**		**0.0265**	**0.00363**	**0.00348**
75th Percentile		**5.17**	**0.396**	**0.35**		**0.209**	**0.00597**	**0.00436**
90th Percentile		5.80	0.506	0.48		0.510	0.00738	0.00581
Number of sites	0	5	3	5	0	6	3	8
UNSTABLE SITES								
10th Percentile			2.90	0.174			0.0371	0.00141
25th Percentile			**6.68**	**0.226**			**0.074**	**0.00147**
50th Percentile		**58.0**	**7.84**	**1.20**	**0.786**	**3.20**	**0.142**	**0.00792**
75th Percentile			**7.89**	**2.84**			**0.216**	**0.03319**
90th Percentile			9.25	4.25			0.276	0.0355
Number of sites	0	1	5	5	1	2	6	5

Results seem to show no consistent trend between suspended-sediment yields and drainage basin size class in Ecoregions 17, 43 and 46. There are, however, trends within ecoregions.

Median, mean annual suspended-sediment yields increase with drainage basin size in Ecoregion 17 (Table 18); from 3.26 T/y/km^2 for basins between 100 and 1,000 km^2 to 7.26 for basins 10,000 – 100,000 km^2. This pattern is not apparent in the $Q_{1.5}$ yield values for Ecoregion 17. Data for stable or 'reference' sites follow a similar pattern to that of "all sites". Yield values for unstable sites are consistently greater than for stable sites, however, there are an insufficient number of sites within the range of drainage-basin size categories to interpret differences in the data. This is shown in Table 21, where a statistical analysis of significant differences in 'reference' suspended-sediment yields by drainage-basin size generally has an insufficient amount of data in each of the classes.

Table 21 – Summary of attempt to distinguish significant differences in 'reference' suspended-sediment yields by drainage-basin size in Ecoregion 17 using the Mann-Whitney Rank Sum Test. ID = insufficient data. Bold values indicate statistical differences.

Drainage basin size in km^2	Mean annual suspended-sediment yield Significantly different and p-value			
	<100	**100-1000**	**1000-10000**	**10000-100000**
<100	-	ID	ID	ID
100-1000	-	-	**Yes / 0.011**	ID
1000-10000	-	-	-	ID
Observed median	-	2.72	5.83	-
Number of data	1	6	23	3

Drainage basin size in km^2	$Q_{1.5}$ suspended-sediment yield Significantly different and p-value			
	<100	**100-1000**	**1000-10000**	**10000-100000**
<100	-	ID	ID	ID
100-1000	-	-	No / 0.598	ID
1000-10000	-	-	-	ID
Observed median	-	0.116	0.0917	-
Number of data	2	8	18	3

There are more data available in Ecoregion 43 to interpret trends based on basin area. Mean annual suspended-sediment yields appear to increase with drainage basin size in Ecoregion 43, whether considering all sites, or when separating data by relative channel stability. However, statistical analysis of the differences between drainage-basin classes showed that for the most part, these differences are significant only for the largest class (10,000-100,000 km^2; Table 22). In part, this may be due to two factors; the first being the relatively small sample size in this class (5) and the second, that the five sites included in this category drain either badland areas or key regions of landscape disturbance such as coal mining and coal-bed methane production (Table 23). 'Reference' mean annual suspended-sediment yield range from a median value of 1.74

T/y/km^2 in drainage basins smaller than 100 km^2 to 43.2 T/y/km^2 in basins greater than 10,000 km^2. As was the case in Ecoregion 17, this pattern is not found in $Q_{1.5}$ suspended-sediment yield data.

Table 22 – Summary of determination of statistically significant differences in 'reference' suspended-sediment yields by drainage-basin size in Ecoregion 43. Bold values indicate statistical differences.

Drainage basin size in km^2	Mean annual suspended-sediment yield Significantly different and p-value			
	<100	100-1000	1000-10000	10000-100000
<100	-	No / 0.338	No / 0.494	**Yes / 0.036**
100-1000	-	-	No / 0.525	**Yes / 0.006**
1000-10000	-	-	-	**Yes / 0.006**
Observed median	1.74	2.82	3.00	43.2
Number of data	**3**	**20**	**20**	**5**

Drainage basin size in km^2	$Q_{1.5}$ suspended-sediment yield Significantly different and p-value			
	<100	100-1000	1000-10000	10000-100000
<100	-	No / 0.259	No / 0.06	No / 0.393
100-1000	-	-	**Yes / 0.021**	**Yes / 0.037**
1000-10000	-	-	-	**Yes / 0.027**
Observed median	0.479	0.225	0.0639	1.44
Number of data	**3**	**22**	**20**	**5**

Table 23 – The five sites with large drainage areas in Ecoregion 43 that make up the 10,000 – 100,000 km^2 drainage basin class.

State	Station number	Station name	Drainage area (km^2)
MT	06214500	Yellowstone River at Billings	30575
MT	06294500	Bighorn River above Tullock Creek near Bighorn	58052
ND	06354000	Cannonball River at Breien	10619
SD	06400500	Cheyenne River near Hot Springs	22559
SD	06447000	White River near Kadoka	12950

Contrary to the findings in Ecoregion 17 and 43, an increasing mean annual suspended-sediment yield with drainage basin area was not observed for Ecoregion 46. Here, suspended-sediment yields appear to decrease with increasing basin area for both mean annual and $Q_{1.5}$ suspended-sediment yields. This pattern also holds for 'reference' yield data although neither of these trends are statistically significant. There are also an insufficient number of unstable sites to calculate statistical differences by basin size.

5.6 Suspended-Sediment Yield in the Northwestern Great Plains; Ecoregion 43

5.6.1 Level IV Ecoregion 'Reference' Suspended-Sediment Yield

Due to the large number of sites with historical flow and sediment-transport data in Ecoregion 43, estimates of 'reference' suspended-sediment yields were refined to the smaller, Level IV Ecoregion scale. At this reduced scale, there are 24 different Level IV Ecoregions in the Northwestern Great Plains (Figure 26). Table 24 provides a brief description of nine of the Level IV Ecoregions where enough data was available to report results. Many of these Level IV Ecoregions have just a few 'reference' sites, not all of which have available mean daily or maximum flow series data sets from which to calculate target suspended-sediment yields (Table 25). Tables 26 and 27 provide Level IV suspended-sediment yield values for Ecoregions 43a, 43c, 43n and 43w, however just six sets of data were used to calculate yields for 43w, and $Q_{1.5}$ yield for 43p was established from just three values.

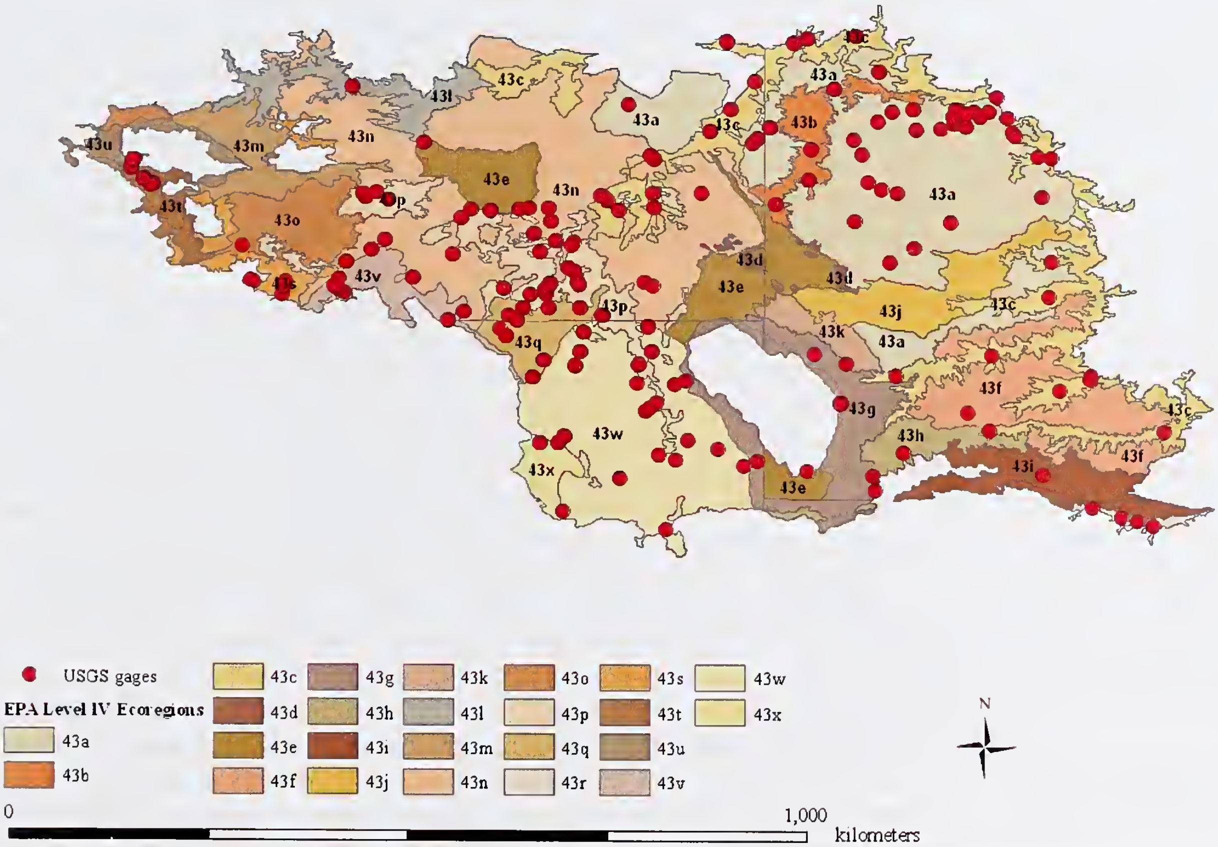

Figure 26 – Level IV Ecoregions of the Northwestern Great Plains, Ecoregion 43.

Table 24 - Brief descriptions of Ecoregion 43 Level IV Ecoregion characteristics where sufficient data are available for calculation of suspended-sediment yield percentiles (Compiled from USEPA, 2007).

Level IV Ecoregion		Primary distinguishing characteristic
43a	Missouri Plateau	The treeless, rolling hills and benches of the **Missouri Plateau** ecoregion were mostly unmodified by continental glaciation. Ecoregion 43a is underlain by the Tertiary Fort Union Formation and Flaxville Gravels. Its soils were derived from residuum and are not so naturally fertile as the till-based soils of the Northwestern Glaciated Plains (42). The potential natural vegetation of the Missouri Plateau (43a) is wheatgrass-needlegrass and contrasts with the grama-needlegrass-wheatgrass that occurs farther west on the more aridic soils of the Montana Central Grasslands (43n). Land use is a mosaic of both rangeland and farmland while, in contrast, the neighboring Montana Central Grasslands (43n) and River Breaks (43c) are dominated by rangeland. Parts of Ecoregion 43a are subject to wind erosion when overgrazed.
43b	Little Missouri Badlands	The **Little Missouri Badlands** ecoregion is highly dissected, sparsely vegetated, and lies within the watershed of the Little Missouri River. Ephemeral, flashy stream flow is typical and has created steep, downcut channels. Both erosion rates and drainage densities are high, and as a result, streams carry heavy sediment loads. Fine-grained, sedimentary rock of the Tertiary Fort Union and the Cretaceous Hell Creek formations outcrop on steep slopes. Vegetation is typically sparse shortgrass prairie; clumps of Rocky Mountain juniper grow on north-facing hillslopes while Northern Floodplain forest grows along drainage ways. Physiography, soils, and land use are distinct from those of the Missouri Plateau (43a), Sagebrush Steppe (43e), and Montana Central Grasslands (43n). The dissected topography, wooded draws, and uncultivated areas of the Little Missouri Badlands (43b) are havens for wildlife. Grazing and recreation are the dominant land uses.
43c	River Breaks	The **River Breaks** ecoregion is composed of very highly dissected terraces and uplands that descend to the Missouri and Yellowstone river systems. Ecoregion 43c is much more rugged than surrounding ecoregions; its steep slopes and heavy, sticky soils often limit its suitability for spring pasture while scarcity of stock water constrains its use for summer grazing. Sparse wheatgrass grows on the heavy, slowly permeable bottomland, threadleaf sedge and needleandthread occur on the gravelly soils of hillslopes, junipers and deciduous trees grow on north-facing slopes of draws, and both little bluestem and buffalograss are found along flatbottomed channels. The ecoregion's dissected topography, wooded draws, and uncultivated areas are havens for wildlife.
43e	Sagebrush Steppe	The **Sagebrush Steppe** ecoregion is nearly level to rolling and is locally surmounted by eroded buttes. Heavy, alkali-rich, slowly permeable, erosion-prone soils are common and support a sparse cover of shortgrass prairie, big sagebrush, and Nuttall saltbush. Grazing is the common land use, but livestock carrying capacity is rather low compared to other Montana rangelands. Much of the area has been severely overgrazed, resulting in erosion. The region has low human population, minimal cultivation, and relatively high concentrations of wildlife. Compared with other nearby ecoregions, Ecoregion 43e has much less dryland farming than the Missouri Plateau (43a), is less dissected than either the River Breaks (43c) or the Montana Central Grasslands (43n), has different potential natural vegetation than the Pine Scoria Hills (43p) or the Montana Central Grasslands (43n), and generally lacks the mesic soils of the Semiarid Pierre Shale Plains (43g) or the Dense Clay Prairie (43k).

Level IV Ecoregion		Primary distinguishing characteristic
43g	Semiarid Pierre Shale Plains	The treeless, rolling **Semiarid Pierre Shale Plains** ecoregion is characterized by heavy, mesic soils derived from underlying Cretaceous sedimentary rock. Mesic soils are rare in Montana and contrast with frigid soils farther north in the Northwestern Great Plains (43). The potential natural vegetation is mapped as wheatgrass-needlegrass and grazing is the predominant land use.
43n	Central Grassland	The **Central Grassland** ecoregion is an unglaciated plain that is dissected by many small, ephemeral or intermittent streams. It is largely underlain by noncarbonate, fine-grained sedimentary rock of the Tertiary Fort Union Formation which become less widespread in the neighboring, but less dissected, Ecoregion 43e. Clayey frigid soils derived from residuum are common and have a ustic-aridic moisture regime; they contrast with the mesic soils of Ecoregion 43q and the less aridic soils of Ecoregion 43a. Potential natural vegetation is gramaneedlegrass- wheatgrass and is distinct from that of the Sagebrush Steppe (43e) and Pine Scoria Hills (43p). Ecoregion 43n is mostly rangeland but irrigated and un-irrigated farms occur in the Yellowstone Valley. Overall, farm land is less common than in the Judith Basin Grassland (43m).
43p	Pine Scoria Hills	The **Pine Scoria Hills** ecoregion is characterized by wooded, rugged, broken land and stony hills. Alluvium and rocky, gravelly colluvium are common. Soils are often poorly developed. In high areas, open ponderosa pine-Rocky Mountain juniper forests grow and have a heavy understory of grasses while, in drier areas, ponderosa pine savanna is found. Stock carrying capacity is low due to rough terrain and lack of water.
43q	Mesic Dissected Plains	The treeless, unglaciated **Mesic Dissected Plains** ecoregion is underlain by shales and sandstones of the Tertiary Fort Union Tongue River Member as well as massive sandstones and shales of the Tertiary Wasatch Formation; the Wasatch Formation is rare elsewhere in Montana. Clinker beds, porcelinite, coal, scoria, and bedrock outcrops occur. Its mesic soils developed from residuum and contrast with the frigid soils farther north in the Northwestern Great Plains (43). The potential natural vegetation is grama - needlegrass - wheatgrass; it differs from the ponderosa pine forest and savanna of Ecoregion 43p and the wheatgrass - needlegrass of the Semiarid Pierre Shale Plains (43g) and Dense Clay Prairie (43k). Today, Ecoregion 43q is mostly used for grazing.
43w	Powder River Basin	The **Powder River Basin** ecoregion covers rolling prairie and dissected river breaks surrounding the Powder, Cheyenne, and upper North Platte rivers. The Powder River Basin has less precipitation and less available water than the neighboring Mesic Dissected Plains (43q). Mule deer, pronghorn antelope, and sage grouse share the plains with livestock. However, oil, gas, and coal deposits are scattered throughout the ecoregion, and mining is exerting a powerful influence on the character of the landscape. Roads and pipelines feed coal-bed methane wells placed in grids 80 acres apart, and vast amounts of underground water reserves are pumped to the surface and wasted in coal-bed methane drilling. The mining fuels conflicts over surface/subsurface property rights and water management in a semiarid region.

Table 25 – Number of 'reference' sites within Level IV Ecoregions with suspended-sediment ratings. Bold values indicate a sufficient number of data for 'reference' value calculations.

	Level IV Ecoregion	Number of sites	Number of stable sites	Number of stable sites with $Q_{1.5}$ yield data	Number of stable sites with mean annual yield data
43a	Missouri Plateau	30	15	**13**	**12**
43b	Little Missouri Badlands	6	2	2	2
43c	River Breaks	31	11	**8**	**8**
43e	Sagebrush Steppe	4	2	2	2
43f	Subhumid Pierre Shale Plains	1	0	0	0
43g	Semiarid Pierre Shale Plains	12	3	1	0
43h	White River Badlands	1	0	0	0
43i	Keya Paha Tablelands	2	1	0	0
43l	Missouri Breaks Woodland-Scrubland	1	0	0	0
43m	Judith Basin Grassland	1	1	0	0
43n	Montana Central Grasslands	34	16	**10**	**8**
43o	Unglaciated Montana High plains	2	1	1	1
43p	Pine Scoria Hills	14	8	3	3
43q	Mesic Dissected Plains	9	4	1	3
43r	Niobrara River Breaks	6	2	0	0
43s	Non-calcareous Foothill Grassland	6	3	0	0
43t	Shield-Smith Valleys	10	4	1	1
43v	Pryor-Big Horn Foothills	5	3	2	2
43w	Powder River Basin	22	8	**6**	**6**
43x	Casper Arch	2	0	0	0

Table 26 – Suspended-sediment yields at the $Q_{1.5}$ for Level IV Ecoregions within Ecoregion 43 where there are sufficient data. Note the number of observations used to calculate values.

ALL SITES

	Suspended-sediment yield at $Q_{1.5}$ in T/d/km^2								
	43a	43b	43c	43e	43g	43n	43p	43q	43w
10th Percentile	0.0700	0.1015	0.0380		0.0438	0.0159	0.00891	0.148	0.163
25th Percentile	**0.110**	**0.138**	**0.100**		**1.59**	**0.0661**	**0.0159**	**0.233**	**0.226**
50th Percentile	**0.296**	**0.360**	**0.432**	**0.158**	**1.94**	**0.396**	**0.0761**	**0.418**	**0.910**
75th Percentile	**0.583**	**5.82**	**1.44**		**4.48**	**1.47**	**0.804**	**0.662**	**9.65**
90th Percentile	0.923	7.55	27.4		512	4.06	13.1	0.679	21.6
Number	26	5	25	3	9	23	6	5	17

STABLE SITES

	43a	43b	43c	43e	43g	43n	43p	43q	43w
10th Percentile	0.0336		0.0946			0.0026			0.103
25th Percentile	**0.0912**		**0.156**			**0.0161**			**0.207**
50th Percentile	**0.266**		**0.323**			**0.0419**	**0.0136**		**0.225**
75th Percentile	**0.423**		**0.631**			**0.259**			**0.255**
90th Percentile	0.603		32.4			0.494			0.304
Number	13	2	8	2	1	10	3	1	6

UNSTABLE SITES

	43a	43b	43c	43e	43g	43n	43p	43q	43w
10th Percentile	0.211		0.0788		0.821	0.163			0.908
25th Percentile	**0.260**		**0.981**		**1.62**	**0.578**			**1.04**
50th Percentile	**0.367**	**5.82**	**1.44**		**1.83**	**1.33**			**3.75**
75th Percentile	**0.628**		**9.31**		**2.98**	**2.85**			**16.6**
90th Percentile	0.762		30.6		4	4.60			25.8
Number	8	3	12	1	6	10	2	2	9

Table 27 – Mean annual suspended-sediment yields for Level IV Ecoregions within Ecoregion 43 where there are sufficient data.

ALL SITES									
	Mean annual suspended-sediment yield in T/y/km^2								
	43a	**43b**	**43c**	**43e**	**43g**	**43n**	**43p**	**43q**	**43w**
10th Percentile	1.23	4.33	1.13		2.75	1.11	0.251	4.33	2.04
25th Percentile	**2.23**	**5.59**	**3.46**		**5.59**	**1.97**	**0.560**	**5.52**	**5.95**
50th Percentile	**3.15**	**43.0**	**11.6**	**19.7**	**45.8**	**15.5**	**1.26**	**8.19**	**18.2**
75th Percentile	**8.00**	**127**	**38.3**		**108**	**41.5**	**8.91**	**14.2**	**81.1**
90th Percentile	15.9	164	286		1202	78.6	89.1	19.9	198
Number	21	6	24	3	7	22	6	7	16
STABLE SITES									
	43a	**43b**	**43c**	**43e**	**43g**	**43n**	**43p**	**43q**	**43w**
10th Percentile	1.20		1.19			0.218			1.04
25th Percentile	**1.89**		**1.43**			**1.20**			**1.99**
50th Percentile	**3.02**		**3.09**			**2.27**			**3.19**
75th Percentile	**6.59**		**9.07**			**3.25**			**5.95**
90th Percentile	7.88		229			15.6			7.62
Number	12	2	8	2	0	8	3	3	6
UNSTABLE SITES									
	43a	**43b**	**43c**	**43e**	**43g**	**43n**	**43p**	**43q**	**43w**
10th Percentile	2.55		10.4		16.3	15.8			18.9
25th Percentile	**4.30**		**12.0**		**35.3**	**19.2**			**21.5**
50th Percentile	**6.23**		**29.5**		**47.4**	**34.1**			**60.3**
75th Percentile	**12.5**		**114**		**78**	**70.1**			**188**
90th Percentile	15.2		300		131	121			208
Number	7	4	12	1	4	10	2	2	9

For a TMDL practitioner tasked with developing sediment targets in Ecoregion 43, a determination would have to be made whether to use 'reference' values calculated over the entire ecoregion or to use values based on the Level IV results. Tests for significant differences between suspended-sediment yields for stable and unstable channels within the Level IV Ecoregions showed mixed results (Table 28). Regions 43n and 43w show significant differences (at the 0.05 level) for both annual values as well as those at the $Q_{1.5}$, while only mean-annual 'reference' values are significantly differently from unstable values for region 43c. This indicates that the Level IV 'reference' values are valid for use within the regions where statistical significance was attained and only for the parameters indicated (Table 28).

To provide some additional guidance in this matter, statistical tests of significance were carried out to determine whether Level IV suspended-sediment yield values could be differentiated from Level III values for Ecoregion 43 at the 0.05 level of significance (p-value). Ecoregion 43 suspended-sediment at the $Q_{1.5}$ for all sites was calculated to be 0.423 T/d/km^2 and the mean annual suspended-sediment was 8.95 T/y/km^2. In these cases, none of the Level IV values are significantly different than the Level III (Table 29). There is not necessarily a reason why the Level III and Level IV values should be different as the data come from the same population (Ecoregion 43). The practitioner would likely use the Level IV 'reference' values for regions shown to have significant differences between stable and unstable sites in that region (Table 28; 43c, 43n and 43w). The Level III 'reference' value would then be used for all other parts of Ecoregion 43.

Table 28 – Statistical significance of differences between stable and unstable suspended-sediment yields for selected Level IV Ecoregions using the Mann-Whitney Rank Sum Test. Only significant values should be used in developing 'targets' for sediment.

Level IV Ecoregion	$Q_{1.5}$ suspended-sediment yields					
	Statistically significant difference between stable and unstable yield values	Stable		Unstable		p value
		Observed median	Number of data	Observed median	Number of data	
43a	No	0.367	8	0.266	13	0.18
43c	No	0.323	8	1.44	12	0.153
43n	Yes	0.0419	10	1.33	10	0.003
43w	Yes	0.225	6	3.75	9	0.002

Level IV Ecoregion	Mean annual suspended-sediment yields					
	Statistically significant difference between stable and unstable yield values	Stable		Unstable		p value
		Observed median	Number of data	Observed median	Number of data	
43a	No	3.02	12	6.23	7	0.19
43c	Yes	3.09	8	29.5	12	0.019
43n	Yes	2.27	8	34.1	10	0.003
43w	Yes	3.19	6	60.4	9	0.002

Table 29 – Tests of statistical significance (denoted by p-values) of the difference in medians between 'all' Ecoregion 43 values (0.423 T/d/km^2 $Q_{1.5}$ suspended-sediment yield and a mean annual suspended-sediment yield of 8.95 T/y/km^2) and the associated value for Level IV Ecoregions. ID = insufficient data to carry out statistical test.

Level IV Ecoregion	$Q_{1.5}$ suspended-sediment yield			Mean annual suspended-sediment yield		
	Observed median	Number of data	p-value	Observed median	Number of data	p-value
43a	0.296	26	No / 0.519	3.15	21	Yes / 0.048
43b	3.60	5	ID	43.0	6	ID
43c	0.432	25	No / 0.122	11.6	24	No / 0.702
43e	0.158	3	ID	19.7	3	ID
43g	1.94	9	ID	45.8	7	ID
43n	0.396	23	No / 0.208	15.5	22	No / 0.941
43p	0.0761	6	ID	1.26	6	ID
43q	0.418	5	ID	8.19	7	ID
43w	0.91	17	ID	18.2	16	ID
Ecoregion 43	**0.423**	**131**		**8.95**	**124**	

The sensitivity of Ecoregion 43 mean annual and $Q_{1.5}$ suspended-sediment yield values to sub-sample size was investigated through optimization analysis. Sub-samples of 5, 10, 15, and 20 yield values were randomly chosen 20 times from the complete data sets of Ecoregion 43 suspended-sediment yield values (Table 30). Results of the optimization analysis are provided below in Tables 31 and 32. The 'reference' value (median) calculated from mean annual suspended-sediment data with as few as five sites fell within the 'reference' inter-quartile range for the complete data set 80% of the time; 90% for 10 sites; and 100% for 15 and 20 sites. For $Q_{1.5}$ suspended-sediment yields these values are slightly different, but within a similar range. Given that it is suggested throughout the report that 'target' values for TMDLs should be comprised of the inter-quartile range of the 'reference', these results indicate that results with a low number of observations are, in most cases, reasonable. Instances where sub-sample 'reference' values fell outside of the Ecoregion 43 inter-quartile range are highlighted in yellow. In Ecoregion 43 for example, there is an 80% chance that the 'reference' value obtained from only 5 sites will fall within the reported 'reference' range for the entire data set. This analysis provides an additional measure of the reliability of the 'reference' values for areas with a low number of observations with results fully supporting the tests of significance associated with all data tables.

Table 30 – Ecoregion 43 'reference' mean annual and $Q_{1.5}$ suspended-sediment transport rates.

Percentile	Number of data	$Q_{1.5}$ suspended-sediment yield
25th	50	0.0354
50th	50	0.170
75th	50	0.380

Percentile	Number of data	Mean annual suspended-sediment yield
25th	48	1.52
50th	48	3.07
75th	48	6.51

Table 31 – Optimization analysis carried out using different sub-sample sizes of suspended-sediment transport rates at the $Q_{1.5}$ for Ecoregion 43. Instances where the calculated sub-sample median fell outside the Ecoregion 43 'reference' inter-quartile range (Table 30) are highlighted yellow.

Percentile	Sample size	Scenario number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range	Percent values fell within Ecoregion 43 'reference' inter-quartile range
25th	5	0.027	0.081	0.091	0.280	0.023	0.081	0.033	0.083	0.004	0.023	0.043	0.019	0.019	0.094	0.015	0.014	0.033	0.003	0.004	0.002	0.278	
50th	5	0.043	0.091	0.266	0.336	0.051	0.226	0.077	**0.383**	0.264	0.081	0.074	0.224	0.076	0.266	0.091	0.081	**0.475**	**0.004**	0.091	**0.014**	0.471	80
75th	5	0.122	0.226	1.442	0.479	0.264	0.318	0.091	0.741	0.354	0.097	0.138	0.280	0.264	0.479	0.336	0.280	0.514	0.043	0.432	0.266	1.399	
25th	10	0.015	0.208	0.075	0.152	0.023	0.028	0.014	0.007	0.180	0.015	0.107	0.081	0.075	0.225	0.006	0.007	0.035	0.011	0.141	0.045	0.000	
50th	10	0.220	0.301	0.234	**0.429**	0.090	0.077	0.215	**0.021**	0.272	0.068	0.220	0.223	0.124	0.304	0.089	0.058	0.205	0.215	**0.399**	0.306	0.000	85
75th	10	0.361	0.377	0.832	0.894	0.195	0.367	0.332	0.375	0.342	0.332	0.361	0.465	0.368	0.505	0.380	0.278	0.478	0.573	0.864	0.478	0.000	
25th	15	0.014	0.038	0.058	0.014	0.048	0.086	0.018	0.048	0.021	0.021	0.021	0.006	0.064	0.053	0.089	0.064	0.073	0.266	0.010	0.170	0.261	
50th	15	0.043	0.081	0.264	0.076	0.336	0.226	0.226	0.214	0.103	0.174	0.224	**0.033**	0.266	0.166	0.336	0.224	0.202	**0.388**	0.264	**0.388**	0.355	85
75th	15	0.353	0.159	0.366	0.253	0.453	0.414	0.449	0.389	0.345	0.451	0.406	0.180	0.574	0.345	0.497	0.455	0.393	0.747	0.428	0.588	0.588	
25th	20	0.150	0.092	0.040	0.021	0.030	0.023	0.063	0.014	0.150	0.046	0.021	0.030	0.065	0.076	0.012	0.021	0.066	0.012	0.096	0.164	0.152	
50th	20	0.299	0.327	0.176	0.208	0.079	0.196	0.225	0.121	0.300	0.118	0.219	0.213	0.118	0.199	0.057	0.130	0.188	0.152	0.327	0.349	0.292	100
75th	20	0.525	0.631	0.323	0.327	0.346	0.349	0.363	0.323	0.443	0.424	0.366	0.374	0.288	0.443	0.225	0.270	0.443	0.345	0.476	0.741	0.516	

Table 32 – Optimization analysis carried out using different sub-sample sizes of mean annual suspended-sediment transport rate values for Ecoregion 43. Instances where the calculated sub-sample median fell outside the Ecoregion 43 'reference' inter-quartile range (Table 30) are highlighted yellow.

Percentile	Sample size	Scenario number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range	Percent values fell within Ecoregion 43 'reference' inter-quartile range
25th	5	6.51	0.24	2.15	1.14	1.22	1.30	0.24	1.24	6.30	3.10	4.23	0.80	0.24	1.53	1.07	1.53	1.24	1.07	2.35	1.24	6.27	
50th	5	**6.52**	1.74	2.64	**1.30**	**1.24**	4.23	3.10	3.03	6.32	4.28	6.30	6.32	3.10	1.94	1.66	3.00	2.64	**1.24**	3.10	3.10	5.28	80
75th	5	7.61	6.51	3.03	17.40	1.53	4.28	4.39	3.10	8.71	6.51	8.00	8.00	3.71	4.28	2.90	4.23	17.40	3.15	3.83	6.52	15.87	
25th	10	1.26	0.46	1.79	0.45	2.20	2.20	1.42	1.16	1.79	1.68	1.73	0.81	1.78	0.97	2.20	1.18	1.79	2.90	3.39	1.55	2.95	
50th	10	1.59	2.29	3.01	**1.39**	6.41	5.29	2.97	2.62	4.87	5.52	3.00	**1.41**	4.42	3.03	3.01	2.61	3.43	4.84	5.67	3.09	5.03	90
75th	10	3.30	3.08	5.79	2.73	15.05	8.12	6.39	3.96	15.05	8.17	5.84	2.66	6.25	5.98	6.20	5.70	7.25	8.04	6.76	6.47	12.39	
25th	15	1.37	2.62	1.37	1.41	1.23	1.18	1.49	2.04	2.93	1.62	1.26	2.61	1.39	1.62	1.84	1.80	1.10	1.10	1.22	1.19	1.83	
50th	15	2.35	4.28	2.15	2.87	2.15	2.87	3.15	3.15	4.28	3.03	2.87	3.71	2.90	4.23	3.00	6.03	2.64	1.53	2.35	2.87	4.50	100
75th	15	4.05	6.41	4.31	4.31	4.31	6.51	4.71	6.16	6.67	6.14	3.43	7.42	4.11	6.42	3.99	7.80	3.65	3.46	6.27	5.77	4.37	
25th	20	1.24	1.78	1.20	1.72	1.28	1.78	1.87	1.62	1.63	1.94	2.18	1.83	1.69	2.52	1.89	1.05	1.89	1.12	1.52	1.72	1.46	
50th	20	2.51	3.43	2.14	3.07	2.69	3.63	3.69	2.62	2.95	3.40	3.69	2.95	2.95	3.12	3.05	3.02	3.07	2.51	3.05	3.77	1.63	100
75th	20	4.87	6.59	6.10	6.59	6.15	7.03	6.37	3.94	4.87	6.35	6.59	6.59	6.10	6.51	5.34	5.27	7.71	4.30	5.40	6.79	3.77	

5.6.2 Ecoregion 43 Suspended-Sediment Yield by Specific Drainage Basin

Within the Northwestern Great Plains there are 20 major drainage basins which have between 1 and 26 sites with transport data (Table 33). While there are insufficient data for the calculation of 'reference' suspended-sediment yield values for the majority of these drainage basins, transport rates were calculated using all available data and mapped to examine spatial trends in suspended-sediment yield (Figures 27 and 28). Both mean annual and $Q_{1.5}$ suspended-sediment yield values vary by at least two orders of magnitude between drainage basins within Ecoregion 43: from a median $Q_{1.5}$ suspended-sediment yield of 0.0405 T/d/km^2 in the Missouri-Poplar River Basin to 13.8 T/d/km^2 in the Fort Randall Reservoir Basin (Table 34) and from a median, mean annual yield of 1.53 T/y/km^2 in the Yellowstone River Basin, to 147 T/y/km^2 in the Fort Randall Reservoir Basin (Table 35).

Table 33 – Major drainage basins within Ecoregion 43 and the number of USGS gauging stations with sufficient suspended-sediment sampling data for developing a transport-rating relation.

Watershed	Number of sites	Number of stable sites with $Q_{1.5}$ yield data	Number of stable sites with mean annual yield data
Belle Fourche	9	4	4
Big Horn	6	3	2
Cannonball-Heart-Knife	26	11	10
Cheyenne	15	3	3
Fort Peck Lake	1	0	0
Fort Randall Reservoir	5	0	0
Grand-Moreau	5	1	1
Lake Oahe	6	2	2
Lake Sakakawea	6	2	2
Little Missouri	8	3	3
Lower Yellowstone	17	8	8
Missouri-Poplar	2	1	1
Musselshell	7	1	1
Niobrara	6	0	0
North Platte	3	0	0
Powder	17	0	2
Tongue	23	6	5
Upper Missouri	2	1	1
Upper Yellowstone	16	2	2
White	8	2	1

The availability of data within specific watersheds is variable with several watersheds having just one or two gages with data (such as the Fort Peck Lake Watershed), while others have as many as 26 (such as the Cannonball-Heart-Knife Watershed) (Table 33). Given this range and the number of watersheds with a low number of gages, the reader is cautioned that presentation of these data are potentially useful for visualizing spatial distributions and patterns, but may not be useful for differentiating 'reference' values unless there are a sufficient number of sites. Having provided this caveat, some patterns can be identified.

The Fort Randall Reservoir drainage basin (watershed #6 in Figure 27) has the largest median suspended-sediment yield at the $Q_{1.5}$ when considering all sites in Ecoregion 43 (Table 34). There are no stable or 'reference' sites with available $Q_{1.5}$ in this watershed; therefore this extremely high $Q_{1.5}$ yield value is calculated from two constructed channels (one of which is the Missouri River at Pierre) and three unstable channels (which includes the Bad River). The upper reaches of the Fort Randall Reservoir Basin include Badland areas drained by Plum Creek and the Bad River which have especially high $Q_{1.5}$ yield values of 66 and 32 T/d/km^2.

The next highest median $Q_{1.5}$ suspended-sediment yield values lie within the Powder and White River Basins (drainage basins 18 and 22 in Figure 27), with calculated median yields for all sites of 3.72 and 3.21 T/d/km^2 respectively. Upper portions of the White River Basin also border the Badlands, and again include data from mostly unstable sites (just two stable sites). All suspended-sediment transport rating equations for sites along the White River are characterized by particularly high coefficient values; coefficient values range from 80 to 480, with the lowest coefficient value being located higher in the watershed than the Badlands, the White River at Slim Butte, SD. Such high coefficient rating equation values signify that a high volume of suspended-sediment is transported at all times at these White River sites, even during low flow events. To put these White River rating equation values into the context of Ecoregion 43 (rating equations are discussed further in Section 5.7), the median coefficient value for all sites located in Ecoregion 43 is 7 (more than 11 times smaller than that of the lowest White River site). The Powder River Basin is not affected by the Badlands, yet still transports a large volume of suspended-sediment during high flow events. The Powder River Basin is currently the largest source of coal mined in the United States, and has recently become a source of coalbed methane, extracted by pumping water to the surface to release gas along the coal seam (Wikepedia.org, 2008). Other basins with high $Q_{1.5}$ suspended-sediment yields include the Little Missouri Basin (#10 Figure 27), the Tongue River Basin (#19 Figure 27) and the Cheyenne River Basin (#4 Figure 27) (1.87, 2.33, and 1.71 T/d/km^2, respectively). Coal mining and coalbed methane development are also major land uses in the Tongue and Cheyenne River Basins.

The remaining drainage basins have median $Q_{1.5}$ suspended-sediment yield values between 0.0405 T/d/km^2 in the Missouri-Poplar River Basin (#14 Figure 27) and 0.975 T/d/km^2 in the Upper Yellowstone River Basin (#21 Figure 27). The low $Q_{1.5}$ yield value of the Missouri-Poplar River Basin is more inline with Ecoregion 42 yield values, which it also drains.

Table 34 - Suspended-sediment yield values at the $Q_{1.5}$ for drainage basins within Ecoregion 43; median values are given in red, inter-quartile range in bold. Note the number of observations used to calculate values.

ALL SITES

Suspended-sediment yield at the $Q_{1.5}$ in T/d/km^2

	NUMBER	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	8	0.0383	**0.165**	0.304	**2.02**	8.95
Big Horn	6	0.169	**0.217**	0.371	**0.968**	5.73
Cannonball-Heart-Knife	22	0.0969	**0.244**	0.324	**0.583**	0.954
Cheyenne	9	0.226	**0.898**	1.71	**9.65**	519
Fort Peck Lake	1			0.463		
Fort Randall Reservoir	5	0.0251	**0.0564**	13.8	**31.7**	52.3
Grand-Moreau	5	0.0759	**0.0941**	0.866	**1.44**	2.37
Lake Oahe	5	0.0105	**0.0258**	0.432	**0.514**	3.46
Lake Sakakawea	6	0.0872	**0.142**	0.303	**0.820**	1.12
Little Missouri	6	0.0869	**0.1072**	1.87	**5.27**	7.26
Lower Yellowstone	11	0.0150	**0.0279**	0.103	**0.357**	0.446
Missouri-Poplar	2			0.0405		
Musselshell	3	0.0292	**0.0668**	0.129	**0.144**	0.152
Niobrara	1			0.488		
North Platte	2			0.0579		
Powder	12	0.923	**1.37**	3.72	**22.2**	42.0
Tongue	15	0.00703	**0.0351**	0.233	**0.676**	1.31
Upper Missouri	1			0.0427		
Upper Yellowstone	3	0.575	**0.725**	0.975	**1.21**	1.35
White	8	0.495	**0.922**	3.21	**8.77**	46.4

STABLE SITES

Suspended-sediment yield at the $Q_{1.5}$ in T/d/km^2

	NUMBER	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	4	0.0635	**0.152**	0.233	**0.284**	0.320
Big Horn	3	0.204	**0.260**	0.354	**0.371**	0.382
Cannonball-Heart-Knife	11	0.0762	**0.133**	0.280	**0.451**	0.635
Cheyenne	3	0.225	**0.225**	0.226	**6.86**	10.8
Little Missouri	3	0.081	**0.087**	0.10	**0.12**	0.13
Lower Yellowstone	8	0.0111	**0.0208**	0.0572	**0.131**	0.246
Tongue	6	0.00255	**0.00538**	0.0165	**0.0430**	0.356

UNSTABLE SITES

Suspended-sediment yield at the $Q_{1.5}$ in T/d/km^2

	NUMBER	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	3	0.360	**0.821**	1.59	**2.46**	2.98
Cannonball-Heart-Knife	7	0.202	**0.252**	0.311	**0.510**	0.646
Cheyenne	5	1.03	**1.22**	1.71	**3.75**	7.29
Fort Randall Reservoir	3	17.4	**22.7**	31.7	**48.8**	59.1
Grand-Moreau	3	0.982	**1.16**	1.44	**2.22**	2.68
Little Missouri	3	4.04	**4.71**	5.82	**7.26**	8.12
Powder	11	1.04	**1.69**	4.28	**23.2**	43.9
Tongue	5	0.216	**0.418**	0.690	**1.49**	5.06
White	5	0.820	**0.995**	1.94	**4.48**	14.38

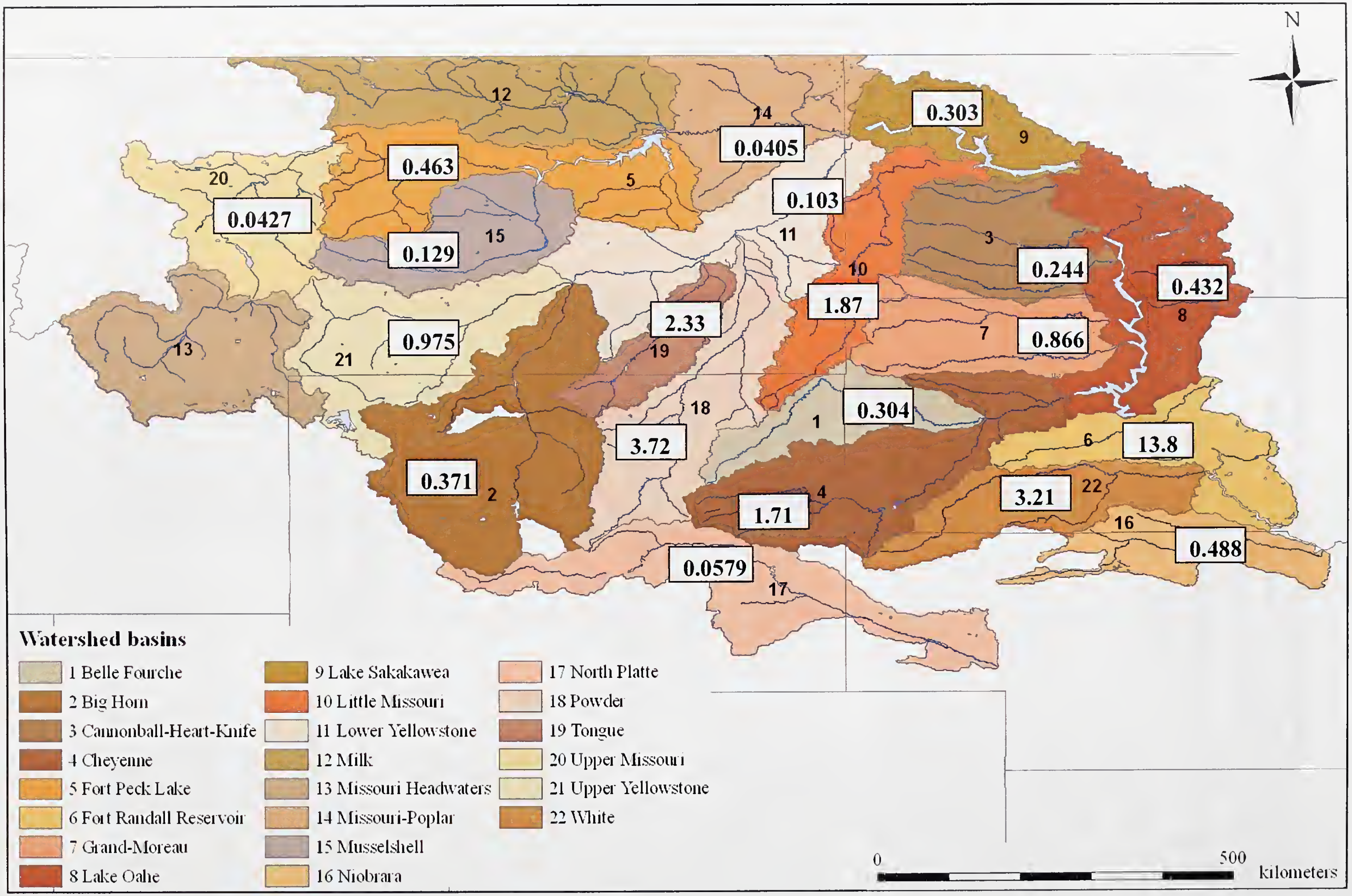

Figure 27 – Median suspended-sediment transport rates at the $Q_{1.5}$ for each major watershed within Ecoregion 43, in T/d/lm^2. Note the number of observations used in calculations, Table 34.

The Fort Randall Reservoir and Powder River drainage basins remain at the top of the list when considering mean annual suspended-sediment yield of all sites in Ecoregion 43, 147 $T/y/km^2$ and 60 $T/y/km^2$, respectively (Figures 27 and 28). Channels in these basins transport large amounts of sediment at both high and low discharges, making them major contributors to suspended-sediment load in Ecoregion 43. 'Reference' suspended-sediment transport rates could not be calculated individually for these drainage basins because the sediment-transport data were derived mainly from unstable channels.

The next four drainage basins with high mean annual suspended-sediment yield values are the Fort Peck, Niobrara, White and Upper Yellowstone River Basins, with yields between 50 and 36 $T/y/km^2$. These values are mostly calculated from unstable channels in all basins but the Upper Yellowstone River Basin; in which case, high yields may be a result of widespread forest fires leaving the ground bare and susceptible to erosion. Fort Peck and Niobrara suspended-sediment yield values are the result of just one site, both of which drain large areas; the Missouri River near Landusky in the Fort Peck Lake Basin drains 106,155 km^2 and the Niobrara River at Mariaville in the Niobrara River Basin drains 25,408 km^2.

At the other end of the spectrum, the Lower Yellowstone River Basin has the lowest mean annual suspended-sediment in Ecoregion 43 of 1.53 $T/y/km^2$, calculated from 11 values, 8 of which are stable or 'reference' sites. It is surprising that this basin has such a low mean annual suspended-sediment yield as it drains several high yield basins, such as the Upper Yellowstone, the Big Horn and the Powder. However the Yellowstone River runs through relatively flat terrain at this stage and is a well developed, re-stabilized braided channel, which no longer experiences bed elevation adjustments. This is also reflected in the channel stability of tributaries such as Rosebud Creek and Armells Creek, the data for which are included in the mean annual yield calculations for the Lower Yellowstone drainage basin.

There are very few drainage basins in Ecoregion 43 where sufficient data exists for the separation of mean annual suspended-sediment yield data by relative channel stability (Table 35). In every case where such calculations are possible (the Belle Fourche, Cannonball-Heart-Knife, Cheyenne, Little Missouri and Tongue River Basins), unstable mean annual yield values are at least twice as large as stable yields (Cannonball-Heart-Knife), and as much as 23 and 26 times in the case of the Belle Fourche and the Little Missouri River Basins. However the number of sites used to calculate these values must be noted, as they are as low as 3 values in some cases.

There were however, two basins with the Ecoregion (Cannonball-Heart-Knife, and the Tongue) where differences between stable and unstable sites were tested statistically to determine if a 'reference' yield for either of these basins would be valid. The only significant differences were for the 'reference' yields in the Tongue River Basin: for mean annual (1.30 $T/y/km^2$; $p = 0.008$) and for $Q_{1.5}$ (0.0165 $T/d/km^2$; $p = 0.017$). Thus, these values could be used as 'targets' by TMDL practitioners within the Tongue River Basin.

Table 35 – Mean annual suspended-sediment yield values for drainage basins within Ecoregion 43; median values are given in red, inter-quartile range in bold. Note the number of observations used to calculate values.

ALL SITES

	NUMBER	Mean annual suspended-sediment yield in T/y/km^2 10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	7	1.22	**2.04**	**3.63**	**26.6**	96.0
Big Horn	5	6.84	**7.61**	**21.1**	**76.9**	78.0
Cannonball-Heart-Knife	17	2.03	**2.76**	**5.85**	**8.00**	18.8
Cheyenne	9	5.50	**8.71**	**23.4**	**214**	738
Fort Peck Lake	1			**49.6**		
Fort Randall Reservoir	5	2.45	**5.27**	**147**	**306**	420
Grand-Moreau	5	3.47	**6.84**	**14.8**	**30.9**	56.1
Lake Oahe	5	0.99	**2.35**	**3.83**	**4.98**	18.8
Lake Sakakawea	5	4.89	**10.6**	**12.5**	**13.9**	16.0
Little Missouri	7	3.34	**4.33**	**9.18**	**110**	160
Lower Yellowstone	11	1.07	**1.23**	**1.53**	**3.40**	18.6
Missouri-Poplar	2			**5.54**		
Musselshell	3	2.42	**5.81**	**11.4**	**15.6**	18.0
Niobrara	1			**41.4**		
North Platte	2			**4.25**		
Powder	15	3.41	**12.6**	**60.3**	**177**	254
Tongue	14	0.27	**1.69**	**5.35**	**17.3**	29.0
Upper Missouri	1			**2.90**		
Upper Yellowstone	3	15.0	**23.0**	**36.3**	**39.8**	41.8
White	6	13.7	**22.7**	**38.7**	**190**	481

STABLE SITES

	NUMBER	Mean annual suspended-sediment yield in T/y/km^2 10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	4	0.686	**1.49**	**2.04**	**2.67**	3.60
Cannonball-Heart-Knife	10	1.68	**2.73**	**3.09**	**6.45**	9.5
Cheyenne	3	6.96	**7.62**	**8.71**	**121**	189
Little Missouri	3	2.40	**3.11**	**4.3**	**4.3**	4
Lower Yellowstone	8	1.09	**1.24**	**1.51**	**2.02**	3.28
Tongue	5	0.200	**0.236**	**1.30**	**2.87**	4.16

UNSTABLE SITES

	NUMBER	Mean annual suspended-sediment yield in T/y/km^2 10th percentile	25th percentile	50th percentile	75th percentile	90th percentile
Belle Fourche	3	12.7	**26.3**	**49.0**	**108**	143
Cannonball-Heart-Knife	6	2.50	**3.53**	**6.04**	**9.28**	13.1
Cheyenne	4	20.6	**22.4**	**29.3**	**79.9**	160
Fort Randall Reservoir	3	179	**227**	**306**	**401**	458
Grand-Moreau	3	18.0	**22.8**	**30.9**	**51.9**	22.3
Little Missouri	4	29.5	**59.9**	**110**	**154**	172
Powder	11	17.0	**40.9**	**143**	**198**	285
Tongue	5	10.7	**18.3**	**22.2**	**31.9**	39.1
White	4	23.3	**28.7**	**38.7**	**94.0**	180.8

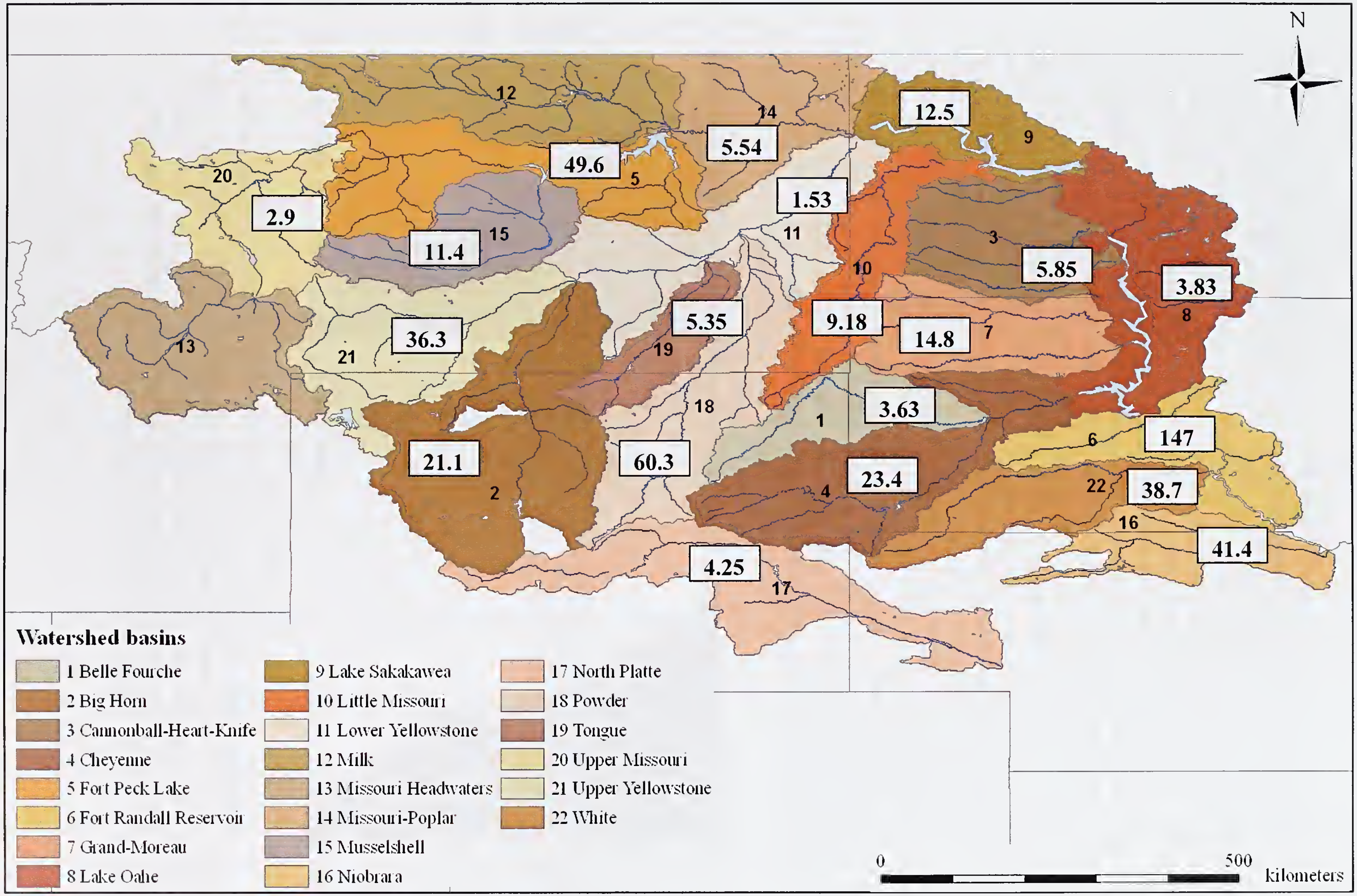

Figure 28 – Median mean-annual suspended-sediment transport rates for major watersheds within Ecoregion 43 in T/y/km^2. Note the number of observations used in calculations, Table 35.

The Fort Randall Reservoir and Powder River Basins are shown to be the highest contributing basins of suspended-sediment in Ecoregion 43 (Figure 29), when data from sites of all channel stabilities are considered. Therefore suspended-sediment yield in these drainage basins is high on a daily basis and during storm-flow events. The Upper Missouri and Lower Yellowstone River Basins remain close to the bottom of the list by ranking of suspended-sediment yield. However, all other drainage basins in Ecoregion 43 rank differently for suspended-sediment yield contributions, dependent on whether $Q_{1.5}$ or mean annual yield is being considered. Data from both the Fort Randall Reservoir and Powder River Basins reflect mostly unstable sites, while data from the Upper Missouri and Lower Yellowstone River Basins reflect mostly stable sites. The relative movement in 'rank' of drainage basin mean-annual and $Q_{1.5}$ suspended-sediment yield between these upper and lower bounds may be a function of many factors. Watersheds with greater variability in terrain elevation and steeper gradient channels are more likely to carry high $Q_{1.5}$ suspended-sediment yields, but may not sustain high yields on a daily basis. Conversely, basins such as the Big Horn River Basin rank higher in terms of mean annual suspended-sediment yield than yields during $Q_{1.5}$, storm-flow events. To give some examples, factors such as land-use, dominant vegetation species and cover (both over surrounding areas and within the riparian corridor), rainfall amount and intensity, and bed and bank material may all affect $Q_{1.5}$ and mean annual suspended-sediment yields within a given drainage basin and should be addressed on a basin specific basis.

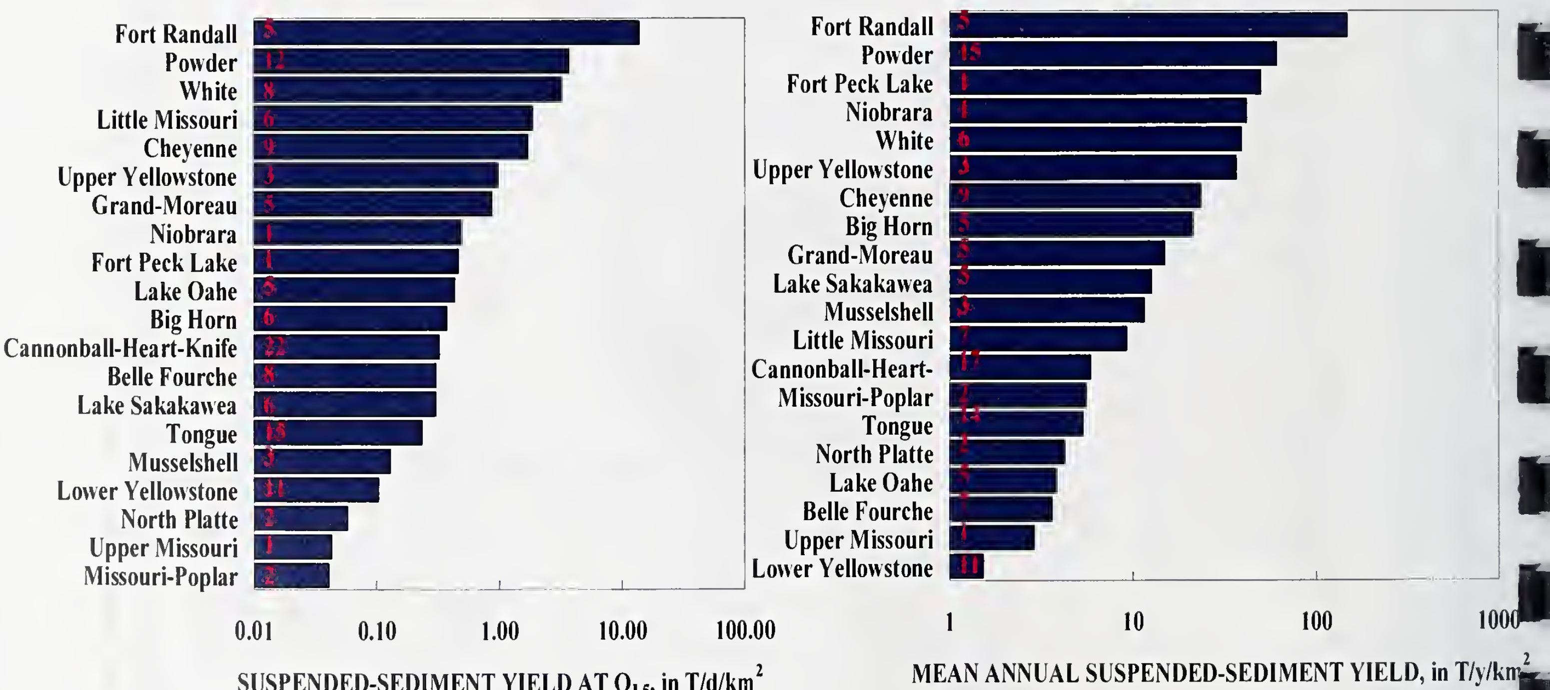

Figure 29 – Median suspended-sediment yield values at $Q_{1.5}$ (left) and mean-annual (right) discharges calculated for *all* sites with available data in major Ecoregion 43 watersheds. Watersheds are ordered from lowest to highest values on the y-axis, with the number of sites used to calculate data given in red.

5.7 Suspended-Sediment Transport Rating Equations

To investigate the possibility of developing 'reference' sediment-transport relations for each ecoregion, the initial, one-stage rating equations for each site were sorted into stable and unstable groups and tested for statistical significance (Table 36). The one-stage rating for a site is the result of a power-function regression between discharge and suspended-sediment load without subsequent refinement of the rating based on trends of residuals (Figures 3 and 4). As these power functions are comprised of two parameters, quartile measures of the coefficient and exponent were calculated for each Level III Ecoregion (Table 37). The median and quartile values of each were then used to solve for suspended-sediment load over a range of discharges. Solved ratings are shown in Figure 30 for each Level III Ecoregion; solid lines represent the median, dashed lines represent the inter-quartile range. As expected, the ecoregion-wide rating equations for unstable sites generally result in order-of-magnitude higher loads than their respective 'reference' ratings for stable sites. Exceptions to this general trend are Ecoregions 17 and 48 where these Ecoregion-wide ratings developed for the two types of channels cannot be differentiated from one another. In Ecoregion 48, this is probably due to a lack of 'reference' sites and available data where only 4 stable sites with flow and transport data (Table 37). Tests of statistical significance (p-values) of differences show a difference in rating equations between stable and unstable channels in Ecoregions 43 and 46, only (Table 36). Low population numbers may be responsible for a lack of statistical significance in differences between stable and unstable channel rating equations in many ecoregions.

Table 36 - Statistical significance of differences between stable and unstable rating equations for Level III Ecoregions.

	Level III Ecoregion					
	15	**17**	**42**	**43**	**46**	**48**
Coefficient						
Significant difference between stable and unstable	No	No	No	Yes	Yes	No
p-value	0.473	0.554	0.086	0.036	0.01	0.958
Observed stable median value	0.0167	0.0971	2.45	5.97	2.71	3.83
Observed unstable median value	0.104	0.102	4.64	12.4	6.52	2.05
Exponent						
Significant difference between stable and unstable	No	No	No	Yes	Yes	No
p-value	0.642	0.324	0.147	<0.001	0.045	0.429
Observed stable median value	1.61	2.07	1.25	1.23	1.06	1.16
Observed unstable median value	1.58	2.16	1.45	1.58	1.21	1.31
Number of stable sites	12	31	16	81	20	5
Number of unstable sites	7	10	16	88	14	12

Table 37 – Rating equation quartile measures for all, stable and unstable sites for selected Level III Ecoregions of EPA Region 8. Equations take the general form of $y = a\,x^{b}$, where y = load in tonnes; x = discharge in m^3/s; a and b are coefficient and exponent determined by regression. Median values are given in red, inter-quartile ranges in bold.

ALL SITES	Ecoregion 15		Ecoregion 17		Ecoregion 42		Ecoregion 43		Ecoregion 46		Ecoregion 48	
	Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent
10th Percentile	0.000166	1.05	0.00488	1.39	0.121	0.983	0.193	1.04	1.37	0.905	0.471	1.19
25th Percentile	**0.0110**	**1.19**	**0.0174**	**1.70**	**1.40**	**1.13**	**2.25**	**1.17**	**2.19**	**0.958**	**0.943**	**1.27**
50th percentile	**0.0448**	**1.58**	**0.17**	**2.04**	**3.28**	**1.26**	**7.04**	**1.40**	**3.51**	**1.07**	**2.05**	**1.43**
75th Percentile	**0.340**	**1.85**	**1.04**	**2.31**	**6.20**	**1.65**	**20.7**	**1.68**	**8.17**	**1.23**	**4.43**	**1.54**
90th Percentile	0.896	2.23	1.88	2.41	9.07	2.12	85.4	2.10	9.84	1.45	8.74	1.66
Number of sites	19	19	47	47	39	39	191	191	38	38	14	14

STABLE SITES	Ecoregion 15		Ecoregion 17		Ecoregion 42		Ecoregion 43		Ecoregion 46		Ecoregion 48	
10th Percentile	0.000900	0.96	0.00730	1.57	0.085	1.01	0.334	1.03	1.03	0.909	1.06	0.99
25th Percentile	**0.0129**	**1.15**	**0.0195**	**1.70**	**0.484**	**1.10**	**2.250**	**1.14**	**1.64**	**0.945**	**1.95**	**1.01**
50th percentile	**0.0316**	**1.47**	**0.0971**	**2.07**	**2.44**	**1.25**	**5.97**	**1.23**	**2.71**	**1.02**	**3.83**	**1.15**
75th Percentile	**0.165**	**1.83**	**0.520**	**2.27**	**4.61**	**1.51**	**12.0**	**1.50**	**4.67**	**1.16**	**4.64**	**1.35**
90th Percentile	0.350	2.16	1.11	2.34	6.33	1.75	30.22	1.79	9.28	1.24	4.99	1.47
Number of sites	12	12	31	31	16	16	81	81	18	18	5	5

UNSTABLE SITES	Ecoregion 15		Ecoregion 17		Ecoregion 42		Ecoregion 43		Ecoregion 46		Ecoregion 48	
10th Percentile	0.00168	1.32	0.00332	1.42	0.671	1.16	0.0548	1.14	3.04	0.949	0.467	1.18
25th Percentile	**0.0100**	**1.53**	**0.00418**	**1.82**	**2.77**	**1.21**	**2.17**	**1.30**	**4.44**	**1.03**	**0.943**	**1.27**
50th percentile	**0.104**	**1.61**	**0.102**	**2.16**	**4.64**	**1.45**	**12.4**	**1.58**	**6.67**	**1.16**	**1.68**	**1.41**
75th Percentile	**0.700**	**1.84**	**0.990**	**2.48**	**7.19**	**2.09**	**37.7**	**1.89**	**9.34**	**1.34**	**4.47**	**1.57**
90th Percentile	4.64	2.42	1.59	2.61	10.9	2.24	127.6	2.30	11.9	1.46	46.0	1.72
Number of sites	7	7	10	10	16	16	88	88	15	15	10	10

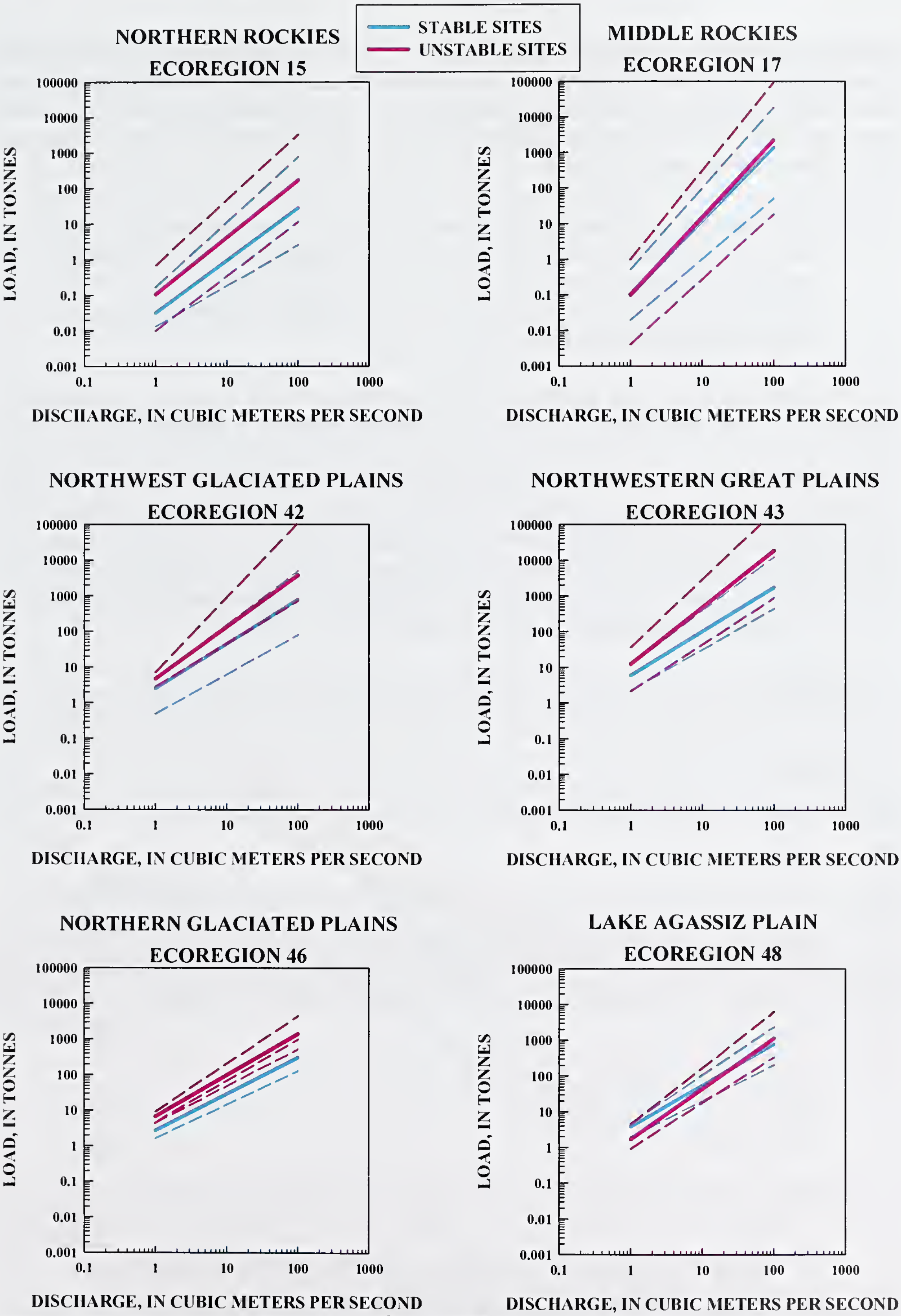

Figure 30 – Median (solid lines), 25th and 75th percentile (dashed lines) rating equations solved for stable (blue) and unstable (pink) channels over a range of discharges.

The median 'reference' ratings are plotted for all Level III Ecoregions in Figure 31 and provide an overview of differences in sediment-transport regimes in these ecoregions. The concept behind this was to attempt to develop a tool by which TMDL practitioners could estimate 'reference' sediment-loads for ungauged watersheds. The 'reference' ratings generally fall into two groups:

1. the mountains, represented by Ecoregions 15 and 17 and characterized by steeper ratings and low coefficients, indicative of low transport rates at low flows, and
2. the plains, represented by all of the other Ecoregions (42, 43, 46 and 48) and characterized by moderately-sloped ratings but higher coefficients, indicative of moderate transport rates at low flows.

In part, these differences are attributable to differences in the resistance of the channel boundary. At low and moderate flows, much of the suspended sediment emanates from the channel boundary where the mountain streams are characterized by coarse, more resistant materials. In contrast, 'plains' Ecoregions are characterized by flatter channel gradients and finer boundary sediments where low flows are still able to entrain and transport sediment. As discharges increase, the rate of increase in sediment transport is greater for the mountain streams than the plains streams, in part due to the contribution of colluvial materials from side slopes until at the highest flows, stable streams from each of the ecoregions are transporting similar loads (Figure 31).

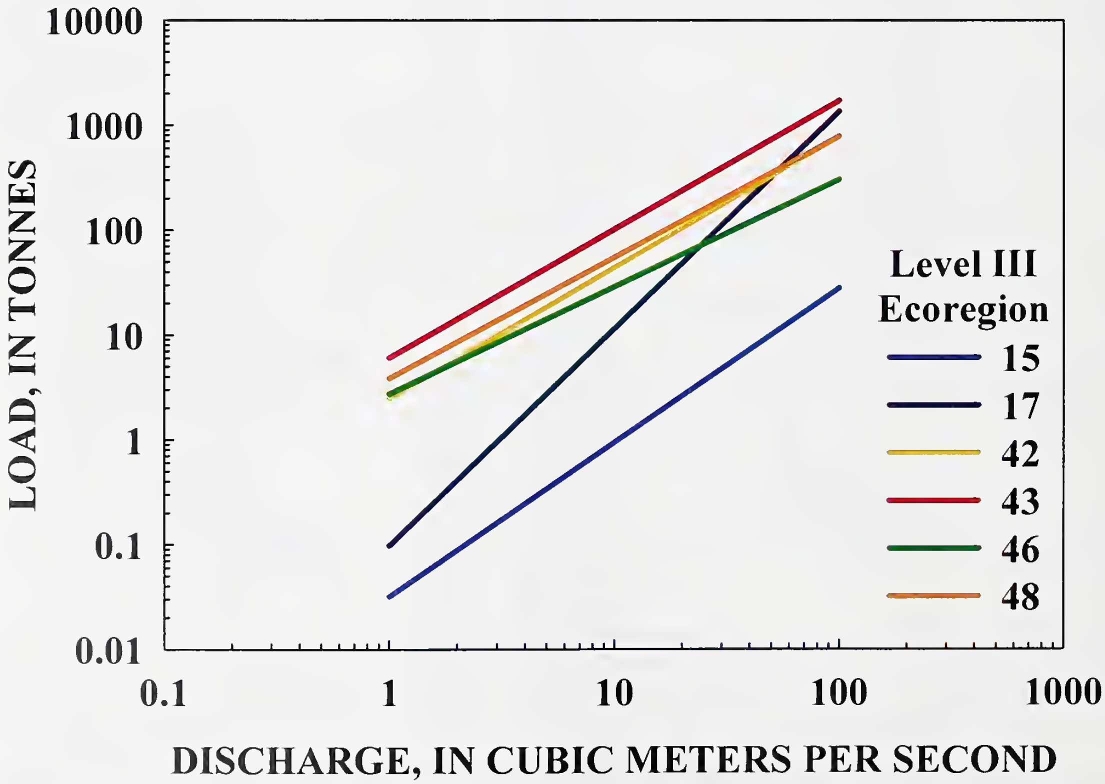

Figure 31 – 'Reference' rating equations for *stable* channels determined from the median value of the coefficient and exponent for each ecoregion.

More specifically, 'reference' rating relations for the Northern and Middle Rockies, Ecoregions 15 and 17, have the smallest coefficients of all other Level III Ecoregions by two orders of magnitude. Such low coefficients indicate generally low suspended-sediment loads at low flows and are typical of mountainous areas. This was also the case for the Blue Ridge (Ecoregion 66) and the Ridge and Valley (Ecoregion 67) mountainous regions of EPA Region 4, where median 'reference' coefficients were the lowest of all Ecoregions in the region. Ecoregion 43 has the largest median 'reference' coefficient value (about 6.0) but is still quite similar to the other plains Ecoregions (Table 37; Figure 31).

Exponent values provide insight into the response of channels during high-flow storm events. Ecoregion 17 has the highest 'reference' rating exponent of the Level III Ecoregions of 2.07, signifying high suspended-sediment loads during storm events. Previously considered unstable (Simon *et al.*, 2001), high exponent values such as this were also calculated for mountainous regions of the Southeast; in fact the median stable exponent for the Blue Ridge (Ecoregion 66) was also 2.07 (Klimetz and Simon, 2006). This may be a clear indication that the rating equation is not solely dependent on the stability of the channel, but is also affected by channel-hillslope interactions and upland processes. Exponent values for Ecoregions 42, 43 and 48 are relatively similar (1.25, 1.23 and 1.35, respectively), with Ecoregion 46 having the lowest exponent of 1.02, a factor of the flat to gently rolling landscape that characterizes this ecoregion.

Tests of statistical significance (p-values) of differences between stable channels for each ecoregion were carried out for the coefficient and exponent values separately (Table 38). Ecoregion 17 coefficient and exponent values are statistically significantly different from all ecoregions except 15, where coefficient values are not found to be different. Ecoregion 15 coefficient is calculated to be significantly different from the plains ecoregions, however Ecoregion 15 exponent values are not different to Ecoregions 42 and 48.

Table 38 – Statistical significance of differences between Level III Ecoregion coefficient and exponent values. Bold values indicate statistically significant differences.

Level III	Significant difference and p-values					
Ecoregion	15	17	42	43	46	48
Coefficient						
15	-	No / 0.076	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / 0.003**
17	-	-	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / 0.002**
42	-	-	-	Yes / 0.005	No / 0.438	No / 0.784
43	-	-	-	-	**Yes / 0.047**	No / 0.166
46	-	-	-	-	-	No / 0.97
Observed median	0.0167	0.0971	2.45	5.97	2.71	3.83
Exponent						
15	-	Yes / 0.007	No / 0.366	**Yes / 0.095**	**Yes / 0.004**	No / 0.126
17	-	-	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / < 0.001**	**Yes / < 0.001**
42	-	-	-	No / 0.984	**Yes / 0.007**	No / 0.417
43	-	-	-	-	**Yes / < 0.001**	No / 0.319
46	-	-	-	-	-	No / 0.126
Observed median	1.58	2.07	1.25	1.23	1.02	1.16
Number of data	12	31	16	81	18	5

Finally suspended-sediment load and associated instantaneous discharge data were converted to yields by dividing by drainage area (in km^2) to produce a unitized 'reference' rating equation for each Level III Ecoregion (Figure 32). To present these in graphical form the unitized ratings are solved for the minimum and maximum water yields sampled in each Level III Ecoregion. When drainage area is taken into consideration, mountainous regions show more obvious separation from plains areas. This distinction between mountains and plains may be a result of the existence of much larger drainage basin areas in these plains Ecoregions. Figure 32 shows that Ecoregions 42, 43, 46, and 48 all produce much lower water yields and, consequently, suspended-sediment yields than the mountainous Ecoregions 15 and 17.

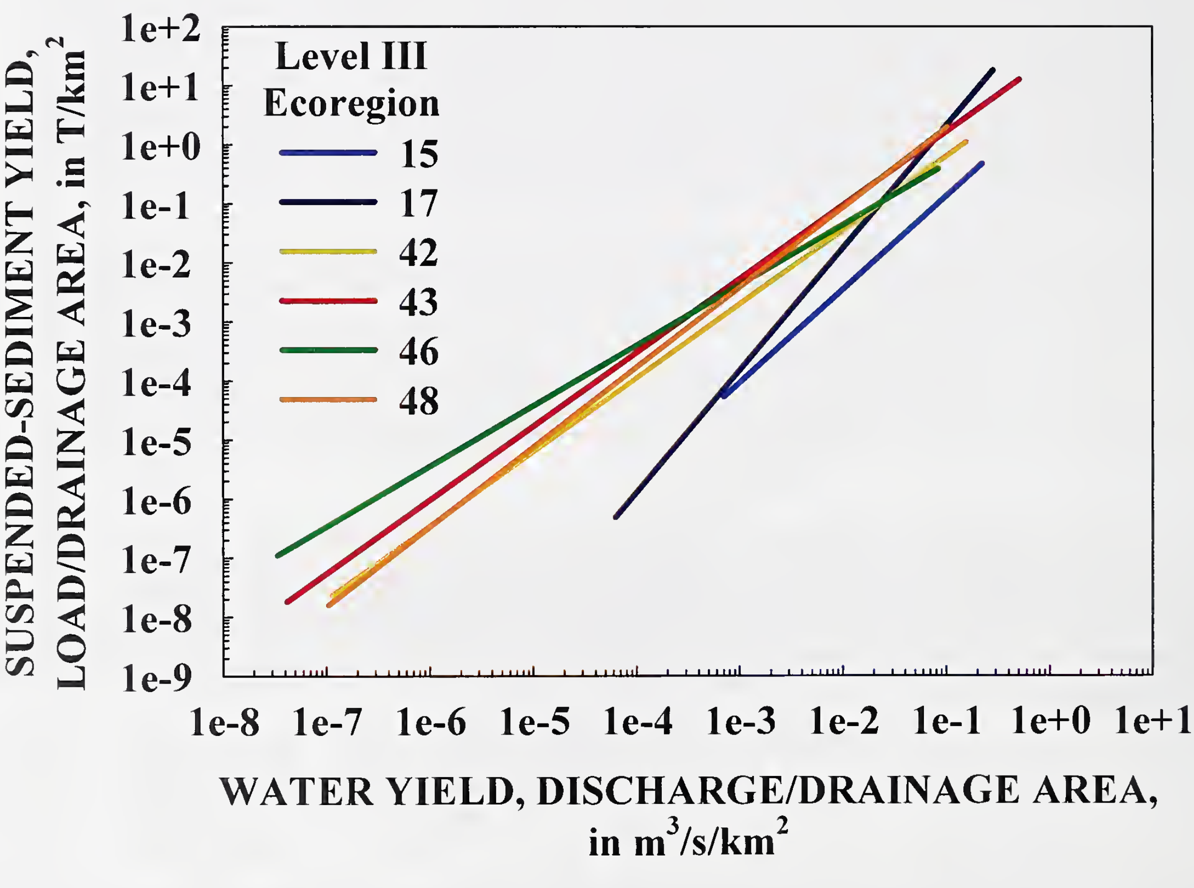

Figure 32 – Unitized 'reference' rating equations for stable channels determined from the median value of the coefficient and exponent for each ecoregion.

5.8 Suspended-Sediment Concentrations

5.8.1 Frequency-Magnitude of Suspended-Sediment Concentration

Suspended-sediment yields, either at the $Q_{1.5}$ or representing mean-annual values have been used thus far to develop 'reference' sediment-transport rates. In this section, the data were re-cast in terms of the frequency and duration that specific concentrations can be expected. It was hoped that data expressed in this way would be useful for developing biologically relevant sediment-transport metrics. As one would expect, median suspended-sediment concentrations (in milligrams per liter) are lower in stable or 'reference' channels at a given percent exceedance than in unstable channels in most Level III Ecoregions (solid lines in Figure 33). Minor exceptions to this can be seen for the Northern and Middle Rockies (Ecoregions 15 and 17, respectively) at very low concentrations, however these are not statistically significant and can be considered similar. This indicates that differences between the frequency of occurrence for stable and unstable streams are more important (significant) at moderate to high flows, with implications for low-flow sampling practices where differences may not be evident.

Problems with the frequency-duration data for Ecoregion 48 exist because data sets from only five stable sites were used to develop the magnitude-frequency relation (Figure 33). In addition, rating relations for stable sites that were used in the calculations were developed from mean-daily discharge data, not the instantaneous flow data (from discharge measurements) that was employed for other sites (L. Tornes, U.S. Geological Survey, written comm., 2007).

Inter-quartile ranges are quite broad within each ecoregion (shown as the dashed lines in Figure 33). The size of the channels in each ecoregion and the range of concentrations of suspended-sediment transport vary greatly both within and between ecoregions. In Ecoregions 17, 42, and 43 inter-quartile ranges of stable and unstable channels do not overlap during low frequency events (those equaled or exceeded 10 % of the time, or high concentration events). Therefore, unstable channels consistently transport higher concentrations of suspended-sediment than stable channels during low frequency events in Ecoregions 17, 42 and 43. There is some overlap of inter-quartile ranges in Ecoregions 15 and 46; however median unstable concentration values are greater than stable 75th percentile concentration values. A distinct separation in the concentration of suspended-sediment transported by stable and unstable channels is noticeable in all Level III Ecoregions with the exception of Ecoregion 48 where differences are more subtle.

There are many ephemeral streams within the dataset of the 'Plains' Ecoregions (The Northwest Glaciated Plains, Ecoregion 42; The Northwestern Great Plains, Ecoregion 43; The Northern Glaciated Plains, Ecoregion 46; and the Lake Agassiz Plains, Ecoregion 48). This greatly affects frequency-magnitude calculations and further calculations with these data such as magnitude-duration and dosage, as zero concentrations are sustained for extended periods of time. For ease of graphical presentation in log scale, days with zero concentration that are associated with zero discharge were assigned a value of 0.01 mg/l. This can be seen as the flattening of the relation to 0.01 mg/l in Figure 33 and subsequent figures.

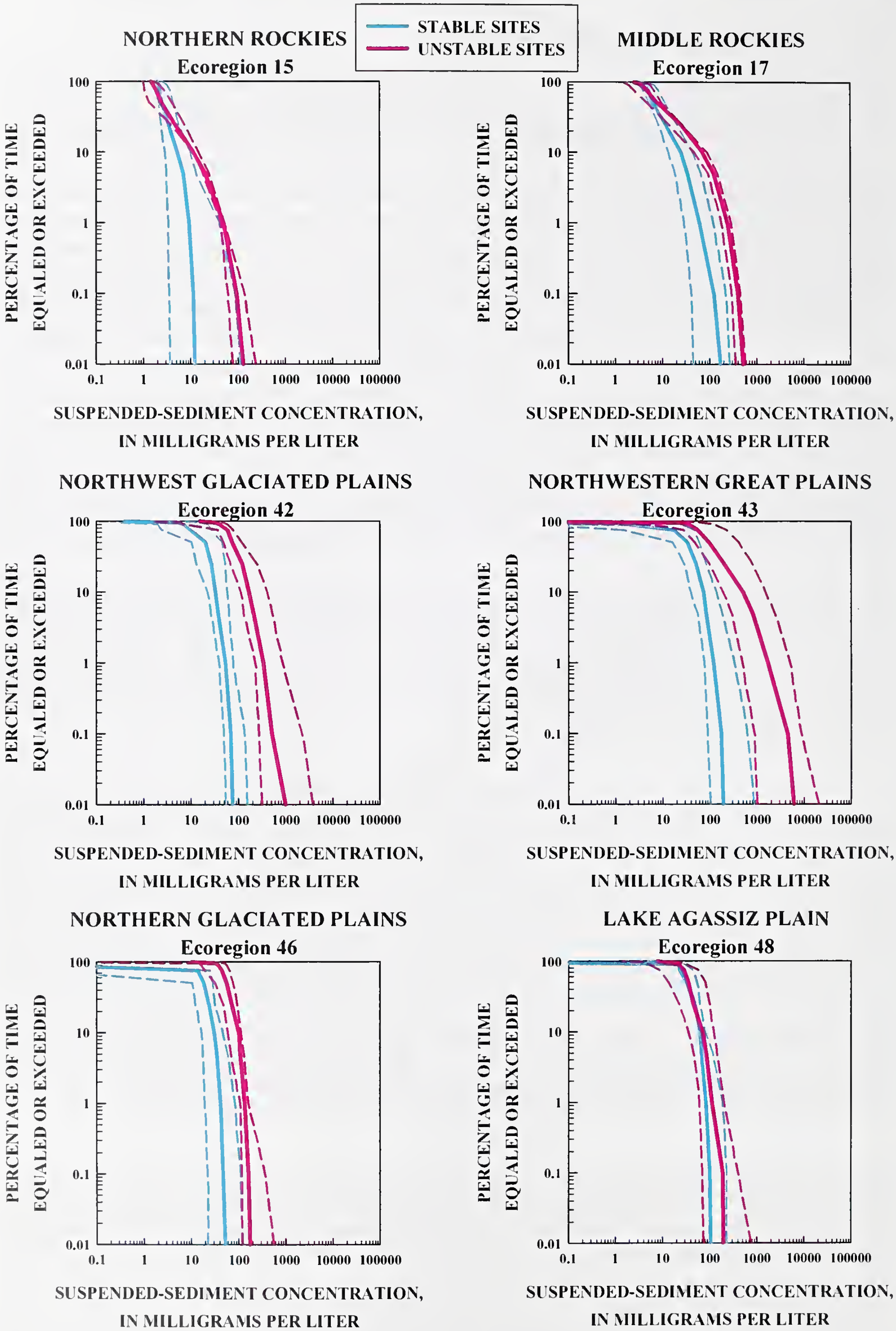

Figure 33 – Inter-quartile (dashed) and median (solid) measures of concentration frequency-magnitude for Ecoregions 15, 17, 42, 43, 46, and 48.

'Reference' frequency-magnitude distributions for the Level III Ecoregions can be seen in Figure 34. These data represent the median distribution for all stable sites within an ecoregion. The benefit of this kind of sediment 'reference' metric is that it can be used by practitioners for comparing a measured concentration at a particular site and a known flow frequency with the 'reference' concentration at that same flow frequency (Table 39). Flow frequency would be obtained either from gage data or from a regional flood-frequency relation.

Ecoregion 15, the Northern Rockies, clearly stands out as having the lowest concentrations for a given frequency than all other Level III Ecoregions. The mountainous rivers making up this dataset are mostly dominated by coarse-grained, boulder-cobble streambeds which provide few fines for entrainment into the water column. Combining dominant coarse grained bed material with the steep gradient of Ecoregion 15 channels which essentially 'flushes' fines out rapidly, the median frequency-magnitude line for stable channels in Ecoregion 15 shows comparatively low concentrations during low frequency events. The median distribution for Ecoregion 15 (Figure 34) also has the smallest range (from 2 to 12 mg/l).in comparison to the other ecoregions. Conversely, the distribution for Ecoregion 17 shows a particularly large range for stable channels, an unexpected outcome for a mountainous area such as the Middle Rockies. Sites making up the Ecoregion 17 dataset, however, represent a combination of montane and foothills streams, some dominated by grazing and forestry activities. Furthermore, Ecoregion 17 is characterized by clay-rich Alfisols as opposed to the coarser Inceptisols of Ecoregion 15. As a consequence there is a broader range of concentrations. This is supported by the generally high exponents in the transport ratings which indicate a more rapid increase in transport as discharge increases. Ecoregion 43 has both the largest low-frequency median stable concentration value (191 mg/l) and the largest range in concentration values (from 0 in ephemeral channels to 191 mg/l). The high median suspended-sediment concentration values for stable channels in Ecoregion 43 may be a result of the highly erosive materials present in the Northwestern Great Plains, such as Badland Areas, poor land-management practices and an overall lack of vegetation.

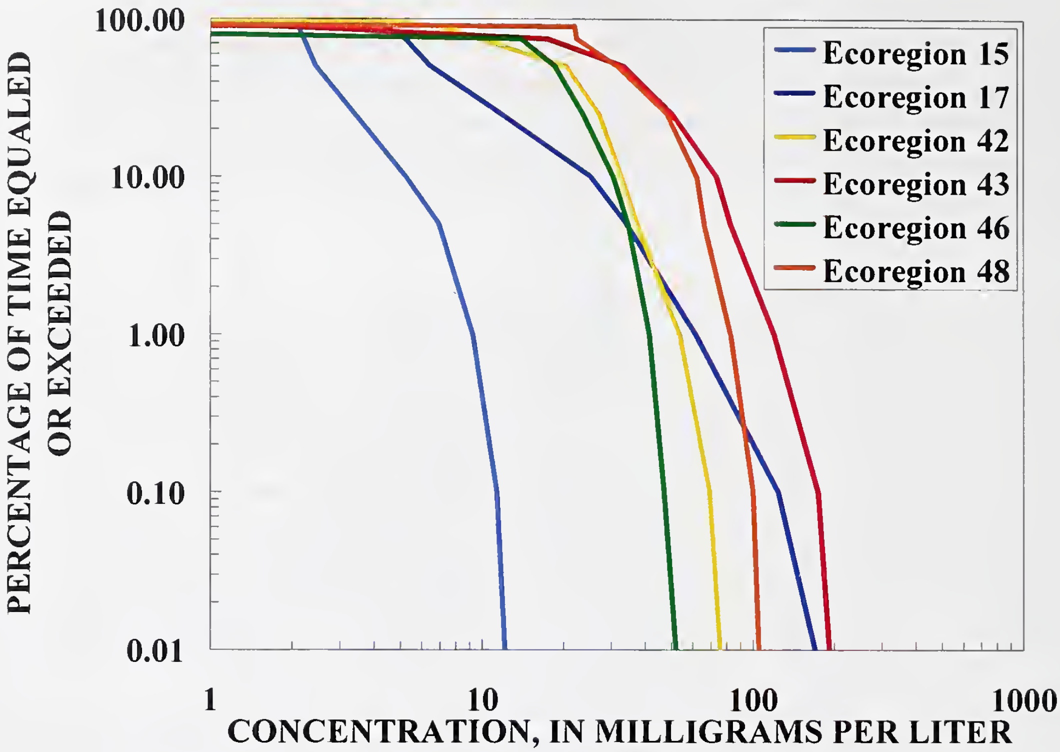

Figure 34 – Percentage of time concentration is equaled or exceeded in stable, 'reference' channels for Level III Ecoregions 15, 17, 42, 43, 46 and 48.

Table 39 – 'Reference' frequency-magnitude concentration distributions for Level III Ecoregions of EPA Region 8.

Time concentration is equaled or exceeded (%)	Number of days per year	Concentration, in milligrams					
		Ecoregion					
		15	17	42	43	46	48
0.010	0.0365	12.1	169	75.5	191	51.9	105
0.100	0.365	11.3	124	69.0	174	46.8	99.8
1	3.65	9.21	61.5	53.5	119	41.3	82.5
5.0	18.25	6.92	34.1	37.4	82.3	34.5	65.9
10.0	36.5	5.21	25.1	32.7	73.4	30.5	61.9
25.0	91.25	3.38	11.7	27.0	50.4	23.5	48.2
50	182.5	2.44	6.43	20.4	33.3	18.5	31.6
75	273.75	2.21	5.19	9.7	17.3	13.8	22.3
90	328.5	2.10	4.33	6.86	1.76	0.00	21.9
95	346.75	2.05	3.99	4.97	0.00	0.00	0.00
99	361.35	1.98	2.89	0.40	0.00	0.00	0.00

5.8.2 Duration of Suspended-Sediment Concentrations

Differences in the duration of suspended-sediment concentrations generally show longer durations at higher concentrations for unstable sites (Figure 35). Ecoregions 15 and 17 stand out from the relations for the 'Plains' Ecoregions with low, almost constant suspended-sediment concentrations for durations from about one month to one year for both stable and unstable streams. These diverge into the expected pattern of higher concentrations in unstable channels for the shorter duration, more extreme events. The durations of specific concentrations are almost always greater for the unstable channels in all of the ecoregions, lending further support to the idea of using these types of data to investigate differences in biologic distribution and function. This is particularly clear in the 'Plains' Ecoregions (42, 43 and 46) where durations for a given concentration in an unstable stream can be an order of magnitude greater than in a stable stream (Figure 35). A similar range between unstable and stable streams is apparent for concentrations at a specific duration. The important point here is that not only do unstable channels transport greater amounts of sediment per unit area (yields), do so at greater frequency, but also maintain high concentrations for longer durations than in stable, 'reference' streams. This is a key element in calculations of dosage, which will be discussed in a later section of this report. There is, however, uncertainty in differentiating between stable and unstable trends as indicated by the spread of the inter-quartile ranges (Figure 35).

Patterns between Level III Ecoregions shown in Figures 35 and 36 are complicated by the number of ephemeral streams present in several of the ecoregions, the consequent number of zero-discharge days and the poor quality of the Ecoregion 48 data. Ecoregion groupings remain similar to that observed in frequency-magnitude plots, with stable channels in Ecoregion 15 transporting the lowest concentrations of suspended-sediment, while Ecoregions 17 and 43 stable channels transport the highest concentration values over the same durations. For instance, a 10 day event in a stable channel in Ecoregion 15 will transport a median suspended-sediment of approximately 7.7 mg/l, while a similar length event in Ecoregions 17 or 43 can transport a suspended-sediment concentration of as much as 47 and 74 mg/l respectively.

The unique duration pattern for the montane ecoregions (15 and 17) can be seen clearly in Figure 36, again reflecting the broad range of durations for low concentrations. In contrast, the 'Plains' Ecoregions display a relatively broader range of concentrations (1 – 20 mg/l) for the moderate and long durations, and again, Ecoregions 17 and 43 show similar concentration-duration traits during extreme events of short duration.

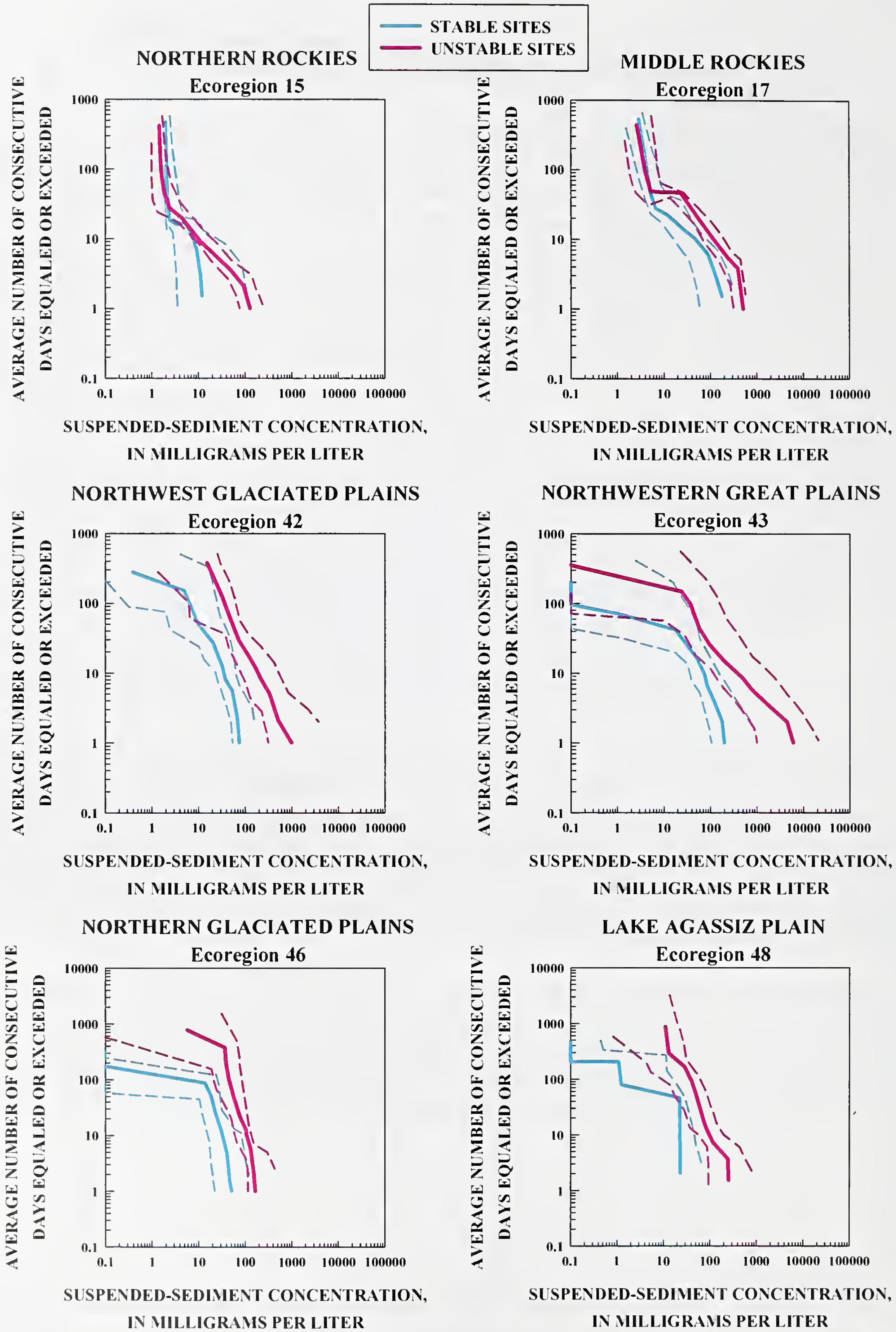

Figure 35 – Inter-quartile (dashed) and median (solid) measures of suspended-sediment concentration frequency-magnitude-duration for Ecoregions 15, 17, 42, 43, 46 and 48.

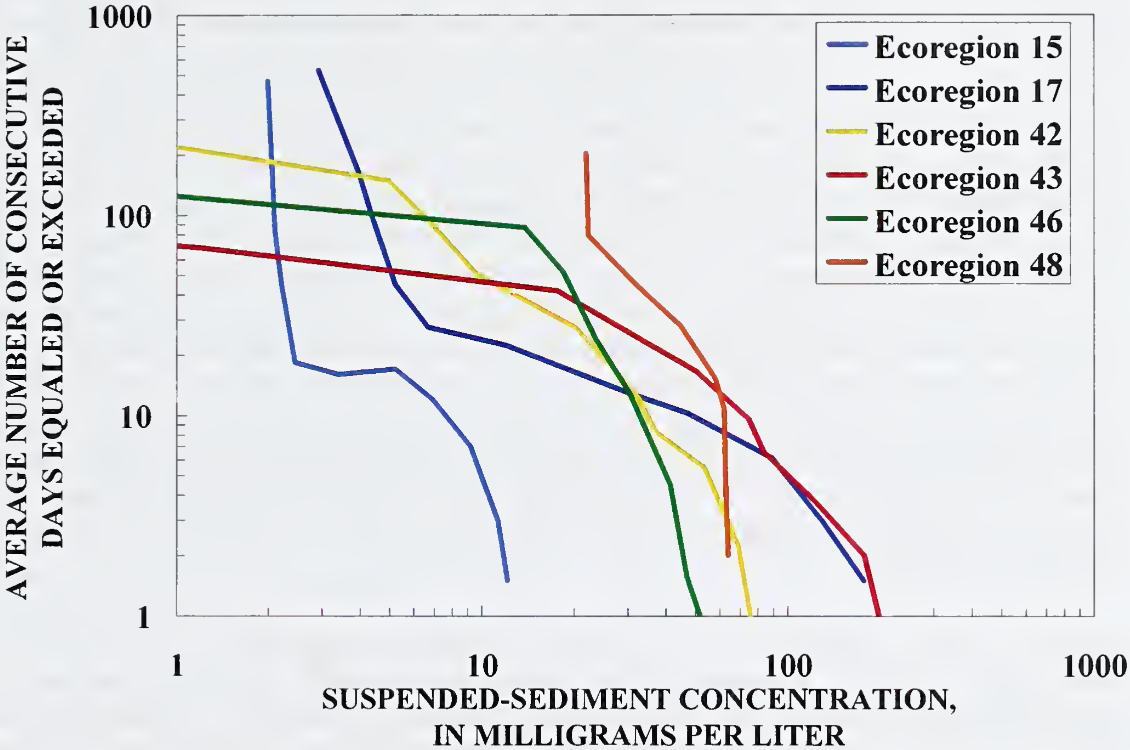

Figure 36 – The average number of consecutive days a given suspended-sediment concentration is equaled or exceeded in stable channels of Level III Ecoregions 15, 17, 42, 43, 46 and 48.

5.8.3 Suspended-Sediment Concentration Dosage and Dosage Impact

'Dosage' may be an important parameter in studies of the impact of a given pollutant on biologic communities. In the case of suspended sediment, dosage is defined as the product of the suspended-sediment concentration and the continuous duration (in number of consecutive days) and would, therefore be expressed in milligram-days per liter (mg-d/l). This metric may be useful to differentiate between the effects, for instance, of a very high, short duration concentration versus a moderate concentration of longer duration. Dosage integrates these two variables (concentration and duration) into a single metric. Quartile values for dosage within a specific ecoregion were calculated from data for each site and sorted into stable and unstable sites within the ecoregion. Maximum dosage values in each ecoregion should be indicative of the concentration and associated flow(s) that has the greatest potential to impact biologic communities. This may be masked to some extent by the effects of using an arithmetic distribution of exceedance classes for logarithmically distributed data. This often results in the maximum value being in the lowest concentration class (ie. concentration exceeded 100% of the time) as opposed to a class(es) of moderate or high concentration because the size of this class is very large (Simon *et al.*, 2004a).

Median and inter-quartile data for all of the Ecoregions are displayed in Figure 37 and show distinct differences between stable (blue) and unstable (pink) sites across the plotted frequency of suspended-sediment concentrations (or flows). The same can be said for the inter-quartile ranges of these data, providing further support of their potential value. As suspended-sediment dose is calculated from magnitude-duration data, the same problems associated with zero discharge days affect these data, as zero dosages cannot be plotted on a logarithmic scale, grey lines represent extensions of existing lines, should flow occur. Across the range of suspended-sediment concentrations, the highest suspended-sediment dosages occur at unstable sites in Ecoregion 43. In terms of dosage in stable, 'reference' streams, Ecoregion 43 generally displays the greatest values across the concentration range (about 200 to 1,000 mg-d/l), although Ecoregion 17 has similar dosage values at high concentrations and flows (low exceedance) (Figure 38). As might be expected, Ecoregion 15 displays the lowest dosage values across the same range of concentration exceedances (10 to 200 mg-d/l) while the remaining 'Plains' Ecoregions have intermediate values (Ecoregion 42 and 43 show intermediate 'reference' dosage values (generally between 100 and 900 mg-d/l).

Application of the 'reference' dosage values for each ecoregion shown in Figures 37 and 38 remains problematic. There is little doubt that the dosage distribution for stable streams is significantly different from the unstable streams across the range of concentrations (or flows). Still, it is unclear as to what part(s) of the distribution are biologically significant. This issue will be further addressed for Ecoregion 43 in the ecological-analysis section of this report (Sections 5.10 and 5.11). Still, peaks in the 'reference' distributions should indicate potentially significant sediment-transport dosage conditions for stable, 'reference' streams within each ecoregion because they represent the maximum product of concentration and duration. Thus, peak dosage values are similar to the geomorphic definition of 'effective discharge' which represents the maximum product of concentration and flow frequency. It may be possible, therefore, to use the peak 'reference' dosage value as a preliminary sediment 'target' that has biologic

implications. Note that the high frequency dosage values (lowest concentrations that are exceeded most of the year) have been shaded-out in gray in the figures as they represent common, background transport rates during low flows. Peak dosage values referred to in this section, therefore, disregard these very low concentration/high-duration values and instead refer to peaks that occur during stormflow.

For example, the maximum dosage for Ecoregion 15 is about 88 mg-d/l across the range of concentrations (or flows), meaning that the product of concentration and duration should not exceed this value in a typical stable stream in Ecoregion 15. Similarly, the preliminary sediment-dosage 'target' for Ecoregion 43 should be about 960 mg-d/l (Figures 37 and 38). Peak sediment-dosage values representing preliminary 'targets', are highlighted for all ecoregions in Table 40. As the calculation of dose is a function of magnitude and duration, zero values occur in some ecoregions due to periods of no flow. These have been removed from Table 40. Of course these values should not be taken as absolute, as it may not be possible to provide a 'reference' suspended-sediment dosage value that is critical to all aquatic species or functional traits in a given ecoregion. This is because ecological requirements and endpoints may be highly variable for different species and assemblages. In addition, there may be other parts of the sediment-dosage distribution that are biologically important. These concepts are explored further in Sections 5.10 and 5.11.

It is interesting to note, that within a given ecoregion, peak dosage shifts towards the less frequent, higher concentration events for unstable sites. For example in Ecoregions 15 and 17 (Figure 37), peak sediment dosages for unstable sites occur at the 0.1% exceedance level in comparison to the 1% exceedance level for stable sites. A similar shift is observed for the 'Plains' Ecoregions where peak sediment dosages for unstable streams range from about the 0.1% exceedance concentration to 10%. This shift is probably due to the increased contribution from channel sources, particularly streambanks which become activated at higher flows.

These order-of magnitude differences in 'reference' sediment dosage between some of ecoregions may explain differences in biologic communities between those ecoregions. This statement is merely supposition at this point because matching biologic data is either not available or is beyond the analytic scope of this project. If we further consider the question of which flows and associated concentrations and dosages are most effective in controlling biologic functions, we could focus on the peak dosage value within each ecoregion as a potential metric. This may allow us to obtain insight into the question of which flow(s) and associated sediment dosage plays the most crucial role in biologic community distribution, stress and impact; the highest concentrations that occur over very short durations, or a moderate concentration that occurs over prolonged periods. Considering the cautionary note provided above, regarding peak values found in the lowest concentration class, we look to the secondary peak of the distribution if the peak is located in the lowest concentration class (100% exceedance). For unstable sites in Ecoregion 15 for example (Figure 37), the concentration class that is exceeded 0.10% of the time (a relatively high concentration) is considered more important than the lowest concentration class that is exceeded 100% of the time.

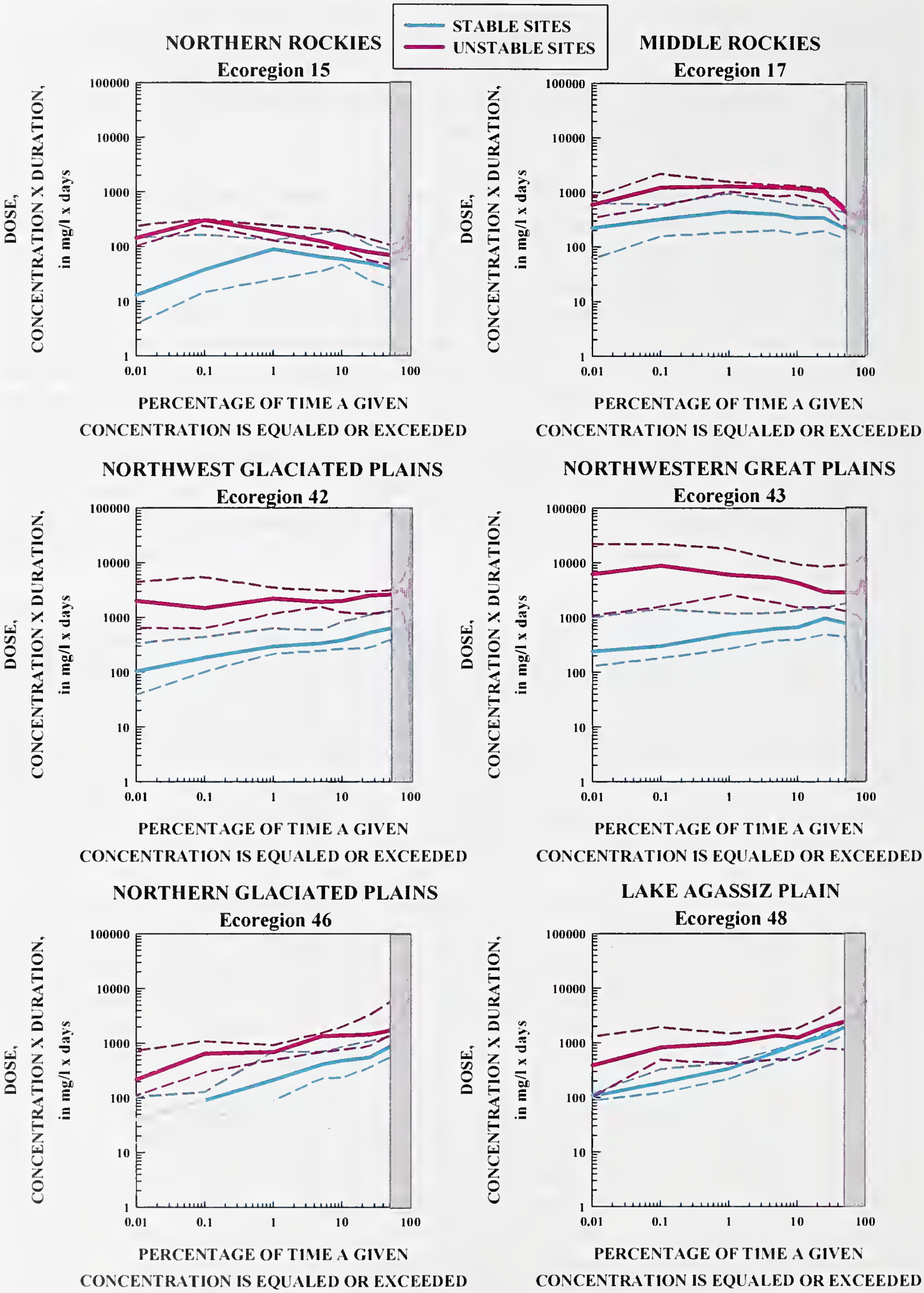

Figure 37 – Inter-quartile (dashed) and median (solid) measures of suspended-sediment dosage (concentration x duration) for the studied Level III Ecoregions.

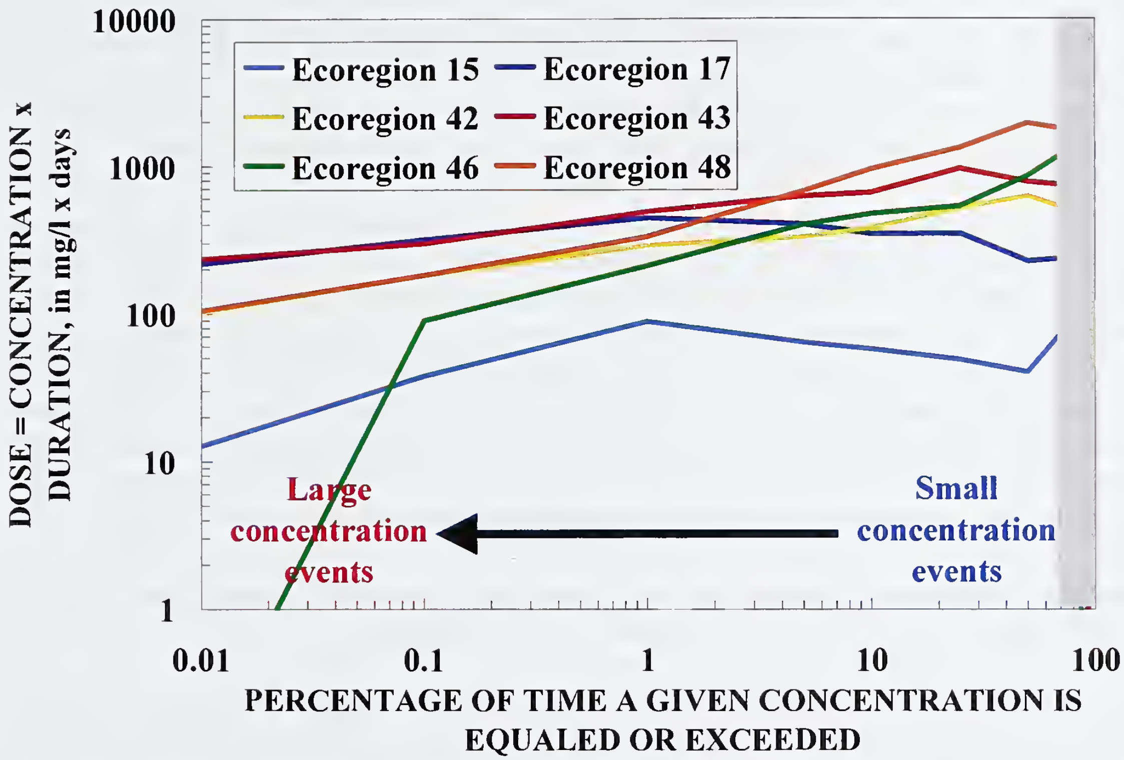

Figure 38 – Distribution of suspended-sediment dosage for a range of concentration exceedance values in stable channels. Grey lines are extensions of calculated values where a large number of ephemeral streams have zero discharge throughout the year and cannot be represented on a logarithmic scale.

Table 40 – 'Reference' sediment dose values for Level III Ecoregions of EPA Region 8. Highlighted values represent the stormflow peak value for each ecoregion, and thus the preliminary 'reference' sediment dosage value.

Time dose is equaled or exceeded (%)	Dose in milligram-days per liter					
	Ecoregion					
	15	17	42	43	46	48
99	935	1413	44.6	-	-	-
95	315	560	835	-	-	-
90	163	368	881	45.4	-	6900
75	81.5	237	509	737	1259	1757
50	40.0	225	623	780	853	1943
25	48.7	348	517	958	533	1328
10	57.6	345	377	657	474	947
5	63.8	400	330	622	399	674
1	88.2	444	291	490	211	332
0.1	37.6	318	182	299	89.4	182
0.01	12.7	218	103	236	-	105

'Reference' sediment dosage peaks at 1% exceedance for the two montane ecoregions (15 and 17), indicating that high flows are potentially important with regards to sediment dosage for sediment-sensitive organisms. In contrast, in the 'Plains' Ecoregions where higher concentrations occur over a broader range of flows, it is the more moderate 30th to 70th exceedance concentration that appears to be the critical value (Figure 38).

The metric, 'dosage impact' represents the arithmetic difference in sediment dosage for stable and unstable conditions at a given concentration exceedance. A plot of these data using concentration exceedance on the abscissa provides a graphical portrayal of the magnitude and distribution of potentially adverse sediment-dosage effects represented by the peaks in the data. We see again that the distributions are largely skewed to the lowest concentration class (highest exceedance) but this is most likely the result of the use of arithmetic-class boundaries (Figure 39). The greatest sediment-dosage impacts occur in Ecoregions 42 and 43 across the entire range of concentration exceedances. This suggests that impairment of biologic communities due to sediment dosage may occur over not only at the high flow-concentration events, but may also be linked to the generally higher concentrations that persist over long periods of time at moderate flows. This appears to be the case with all of the 'Plains' Ecoregions (Figure 39).

Traces for both of the montane ecoregions and Ecoregion 43 show the biggest sediment-dosage impact at the 0.1% exceedance level (Figure 39), again indicating that high flow events are potentially the most critical to sediment-sensitive biota. Lower concentration and flow events do not appear to play an important role. However, dosage impact for Ecoregion 17 remains high to about the 10% exceedance suggesting that sediment concentrations and durations at moderate flows may also be of concern in this Ecoregion.

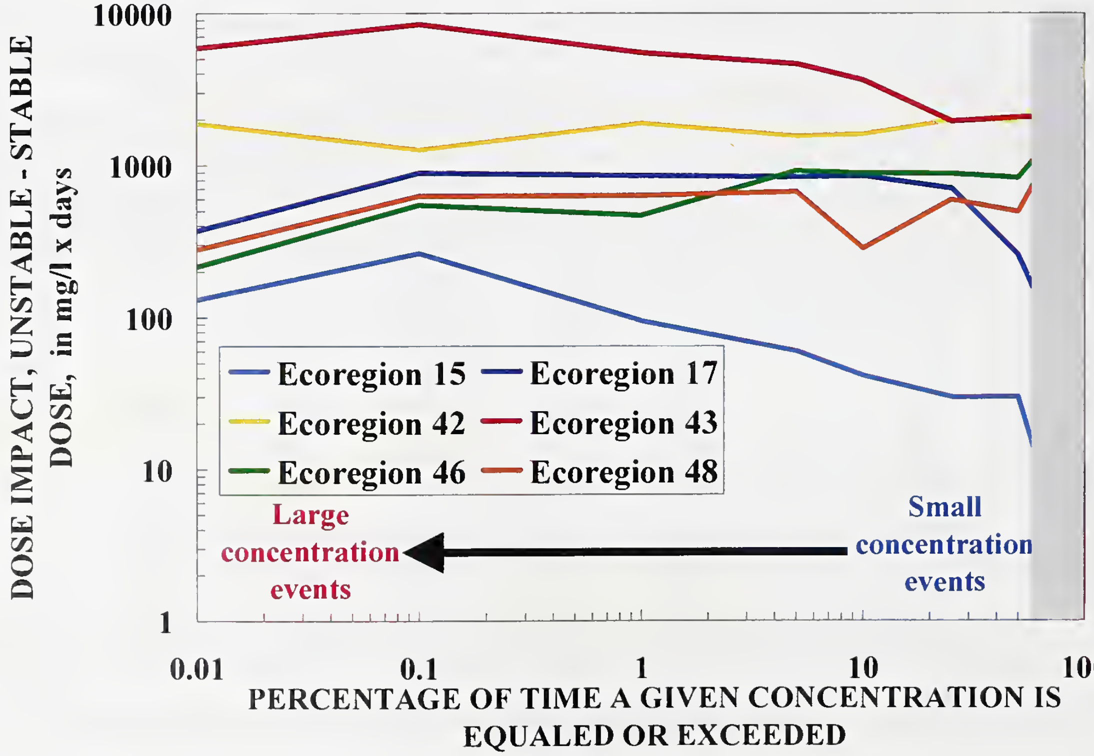

Figure 39 – Suspended-sediment dose impact (unstable – stable dose) for the studied Ecoregions over a range of concentration-exceedance values.

5.9 Trends in Precipitation and Flow: 1900 - Present

Temporal trends in average-annual precipitation and stream runoff were examined for each of the ecoregions included in the study. The purpose of this analysis was to investigate decadal-level variations in runoff as this variable is inherently related to sediment loadings (concentration times discharge). Runoff data were unitized by dividing by drainage area (in km^2) so that basins of different size could be included in the analysis. Data were then expressed as a water yield (in $m^3/s/km^2$). Changes in water yield over the last century may reflect alterations to the landscape (land use), direct modifications to stream channels (ie. channelization, dams), irrigation and changes in precipitation. An attempt was made to incorporate changes in precipitation into the interpretation of changes in runoff or water yield over the past century. The data used in this section only cover a 100-year period and, therefore, are not meant to make inferences about the broader issue of global climate change.

Precipitation trends over the past 100 years are shown in Figure 40 for each of the studied ecoregions. Variations in the 'Montane' Ecoregions (15 and 17) represent the source of many of the 'Plains' streams and are, therefore, particularly important in interpreting variations in runoff in these flatter regions. The Dust Bowl era clearly stands out as below average precipitation between the mid to late 1920's and the late 1930's. Above average precipitation for the 1990's is also apparent. Most recently however, a marked drier period occurred in Ecoregions 15, 17 and 43. Ecoregions 15 and 48 show the most rapid increases in annual precipitation; 0.86 and 0.41 mm/y, respectively (Figure 40). For Ecoregion 15, this converts to an increase of about 3.4 inches over the last century. Only Ecoregion 42 displays a decrease in annual precipitation, and this trend is particularly subtle (-0.08 mm/y).

Trends in water yield over the past century are shown in Figure 41 and show the expected order-of-magnitude differences between long-term rates for the 'Montane' and 'Plains' Ecoregions, with the mountainous area producing more water per unit of drainage area. In the case of water yields, the Dust Bowl era stands out for only several of the ecoregions (15, 43 and 48) and the higher mean-daily flows for the 1990's are apparent only for ecoregions 46 and 48. These differences between trends in precipitation and water yield are probably the result of human influences and disturbances. These differences are more readily apparent by comparing decadal variations in these two parameters. These are shown in a color-coded format in Table 41. What is most interesting to note in comparing these tables is that starting in 1980, water yields in most cases are consistently below the long-term means notwithstanding either average or above average precipitation. This suggests that water withdrawals by irrigation are making a large impact on the amount of water in the streams.

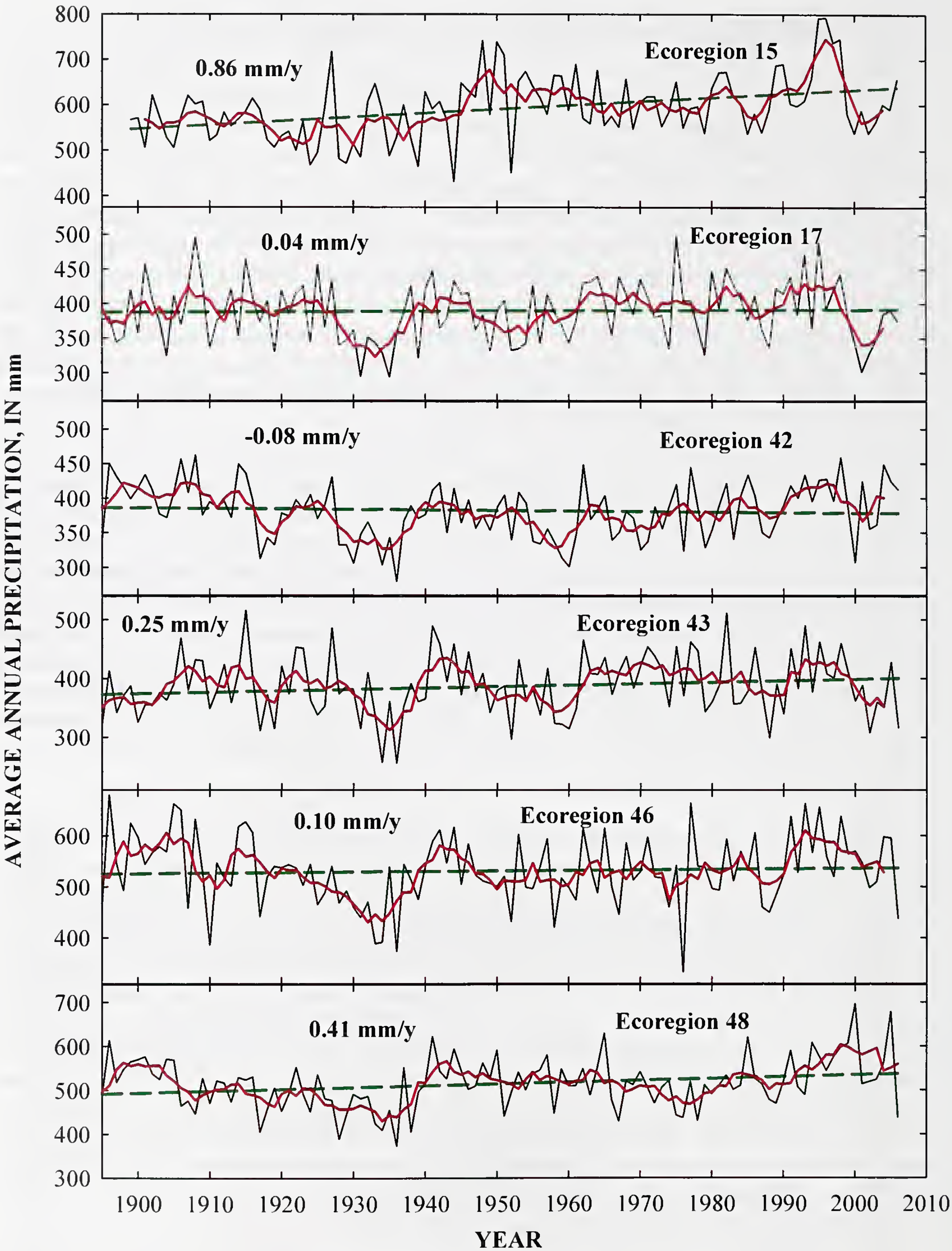

Figure 40 – Trends of average-annual precipitation for the studied ecoregions. The red line is a 5-point moving average and the green-dashed line represents the 100-year trend (also shown is the average annual change in mm/y).

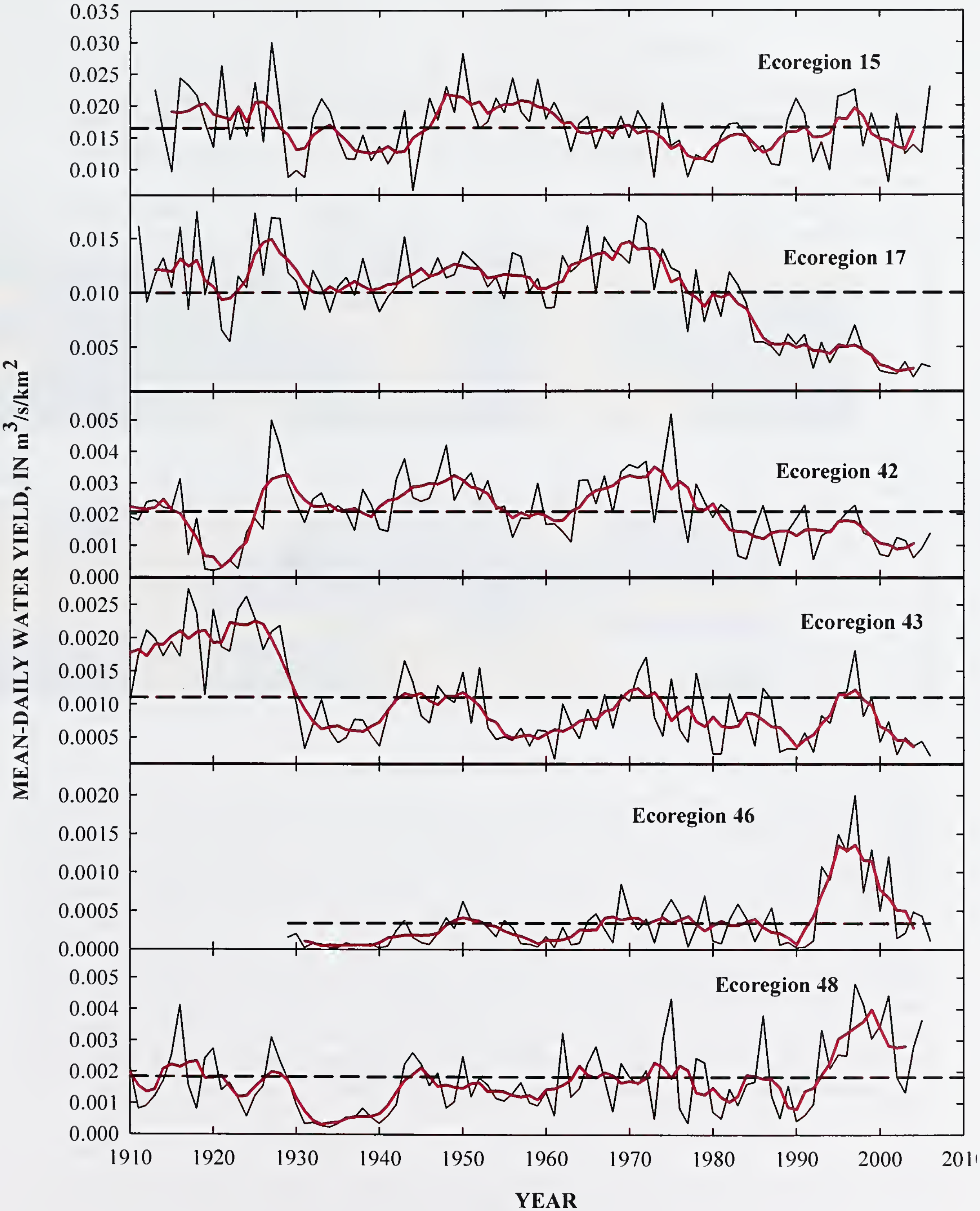

Figure 41 – Trends of mean-daily water yield for the studied ecoregions. The red line is a 5-point moving average; the dashed line is the mean value for all stations over the period of record.

Table 41 – Decadal variations in average-annual precipitation (top) and average-annual water yield (bottom) in the specified ecoregions. Note: '+' signifies above long-term average, "-" signifies below long-term average, and "=" signifies near long-term average.

Ecoregion	1900-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
15	-	-	-	-	+	+	=	=	+	+	=
17	=	+	=	-	=	-	+	=	=	+	-
42	+	=	=	-	=	-	-	=	=	+	+
43	=	+	=	-	+	-	+	+	=	+	-
46	+	=	-	-	+	-	=	=	=	+	=
48	+	=	-	-	+	=	=	-	=	+	=

Ecoregion	1900-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
15	n/a	=	+	-	=	+	=	-	-	+	-
17	n/a	+	+	=	+	+	+	+	-	-	-
42	n/a	-	-	=	+	+	+	+	-	-	-
43	n/a	+	+	-	=	-	-	-	-	-	-
46	n/a	n/a	n/a	-	-	-	=	=	-	+	+
48	n/a	=	-	-	-	-	=	=	-	+	+

Over the past 100 years all but Ecoregions 46 and 48 show a decrease in runoff per unit drainage area (Figure 41). The most striking aspect of the trends for the other four Ecoregions is that since the 1970s or 1980s, water yield (and runoff) has been well below average, with Ecoregion 17 showing the most consistent and largest percent reduction (Figure 42). Water yield data expressed as the percent difference from the mean for Ecoregion 43 shows a reduction of similar magnitude with a short respite during the wet period of the 1990s (Figure 42). Water yields for eastern Ecoregions 46 and 48 which are characterized by large wetland areas show large peaks in between the mid 1990's and into this century where the 5-year moving average peaks at about 100-300 % above the long-term average. This trend is related to large precipitation events and the flooding on the Red River during this period.

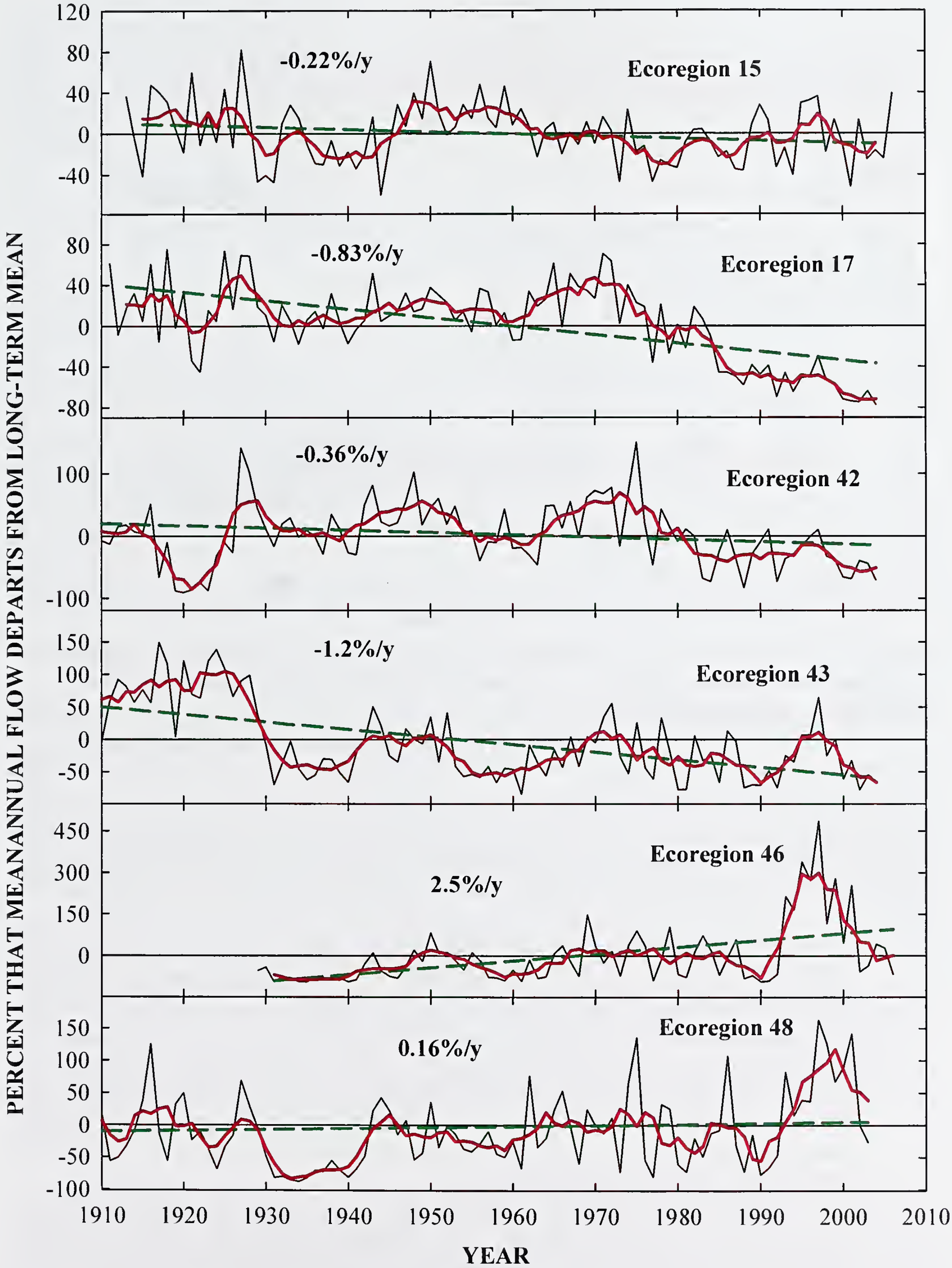

Figure 42 – Trends of percent differences in water yield for the studied ecoregions. The red line is a 5-point moving average and the green-dashed line represents the 100-year trend (also shown in average change, in percent per year, %/y).

The magnitude of the variations in water yield for all of the studied ecoregions is more clearly seen in Figure 43. Here one can observe that variations in water yield between ecoregions follow similar patterns but are of different magnitudes. Ecoregion 15 shows the most subtle variations around the long-term average perhaps because of the least human disturbance, whereas variations in Ecoregions 46 and 48 seem particularly amplified.

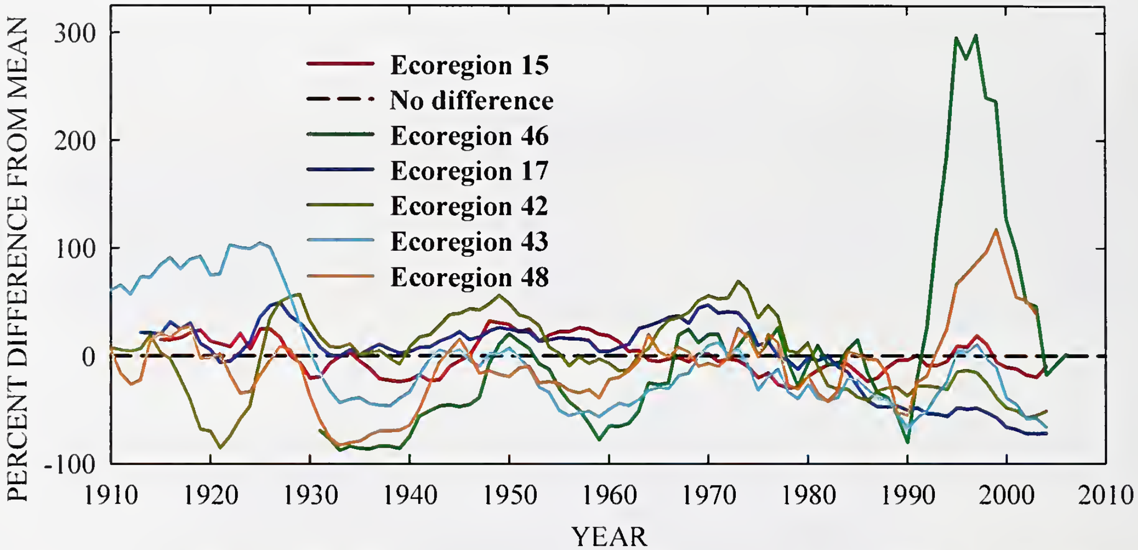

Figure 43 – Trends of percent differences in 5-year moving averages of water yield for all of the studied ecoregions. Note that the pattern of variations is similar, although of different magnitudes.

To make further inferences regarding changes in water yields over the past century, the effects of variations in precipitation were considered by investigating trends in water yield per unit of precipitation. This was done by dividing the annual water-yield data by mean-annual precipitation and should highlight water yield and runoff changes due to other controls. Results show three different types of trends over the period (Figure 44):

1. Ecoregion 15 which displayed the most subtle changes in water yield, also show only a mild, linear but consistent decrease in water yields per unit precipitation. This could be due to numerous factors of both 'natural' and anthropogenic origin;
2. Ecoregions 17, 42 and 43 display more striking decreases in water yield per unit precipitation, particularly since the 1970s to early 1980s, when precipitation was average, or above average. This supports the previously stated interpretation that the decreases in water yield (and runoff volumes) are the results of anthropogenic changes, including water withdrawals for irrigation and retention of water in the growing number of headwater dams.
3. The eastern-most Ecoregions, 46 and 48 show increased water yields per unit of precipitation. The trend for Ecoregion 46 has been in place since the close of the Dust Bowl period in the 1930s while the trend for Ecoregion 48 is more recent, extending back to the 1960s. Without additional information regarding land use practices and alterations to stream channels (ie. channelization) interpretation as to the causes of this trend would be mere speculation.

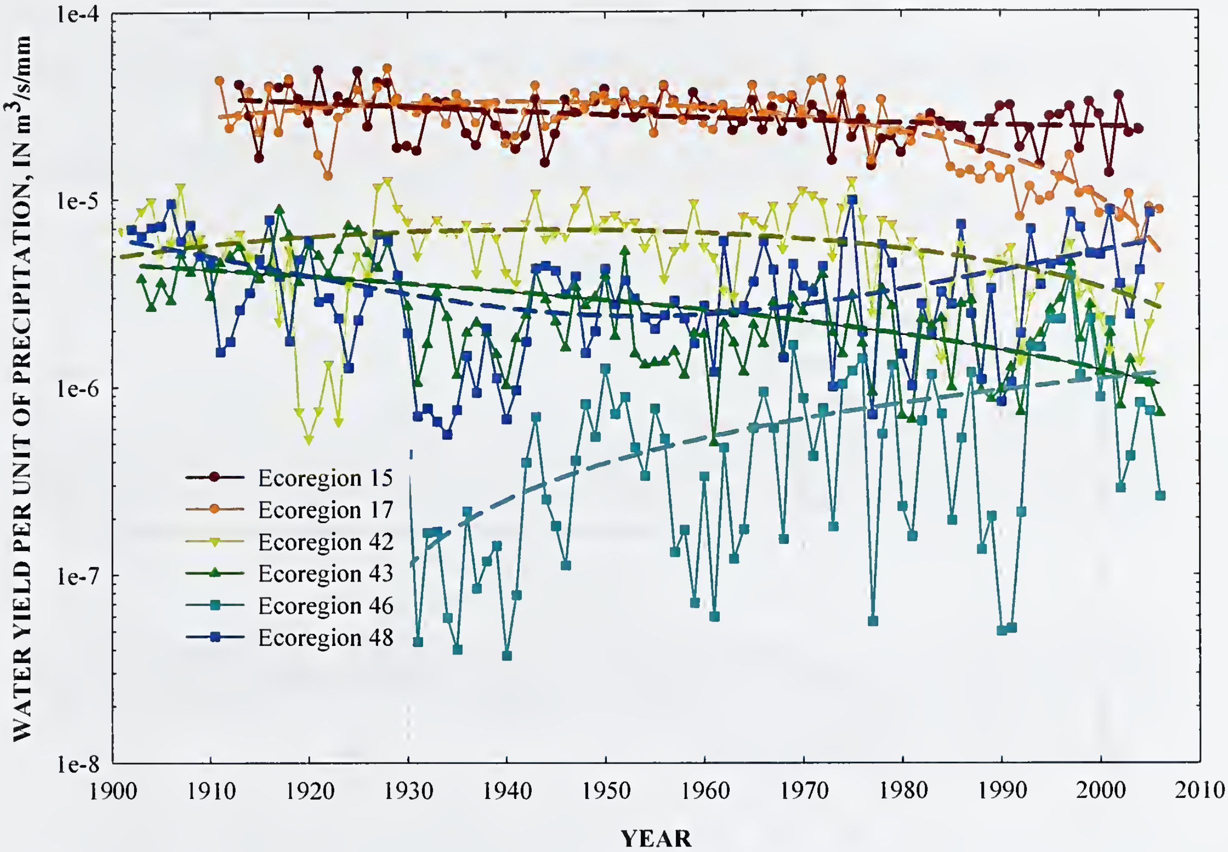

Figure 44 – Trends in average-annual water yield per unit of precipitation over the past century for all of the studied ecoregions.

Today runoff production per unit drainage area and unit precipitation has drastically changed over the last century in some of the Ecoregions (Figure 44). At the turn of the 20^{th} century, the 'Montane' Ecoregions (15 and 17) carried substantially more water than the 'Plains' Ecoregions per unit drainage area and per unit precipitation. Drastic reductions in Ecoregion 17, beginning in the early 1980s have resulted in present-day hydrologic response similar to what conditions were like in Ecoregion 42 at the turn of the 20^{th} century and what present conditions are like in Ecoregion 48. Unitized runoff production in Ecoregion 42, 43 and 48 were quite similar at the beginning of the 20^{th} century but have diverged over the past century such that order of magnitude reductions in Ecoregion 43 has made it hydrologically similar to Ecoregion 46, which experienced similar increases (Figure 44).

At this point we cannot formally provide specific cause and effect answers to these assorted changes over the past century as they are probably the result of a number of important contributing factors, both 'natural' and human induced. As an example, we provide data on the number of dams constructed throughout the region in the past 100 years (Figure 45). About 1600 dams were constructed between 1951 and 1960 in Ecoregion 43 alone. Ecoregions 42 and 43 have the most dams per unit area (about $0.01/km^2$) compared to all of the other ecoregions which, by the first decade of the 21^{st} century have about 0.002 dams per km^2. Given the transformation of much of the region

to agriculture, the construction of thousands of dams, and the impacts of logging, surface mining, coal-bed methane production, channelization and irrigation, it is not surprising that the documented changes in water yield have occurred. It is quite clear, however, that the significant changes in precipitation and water yields have occurred over the past century and that these changes have impacted sediment production and loadings throughout the region.

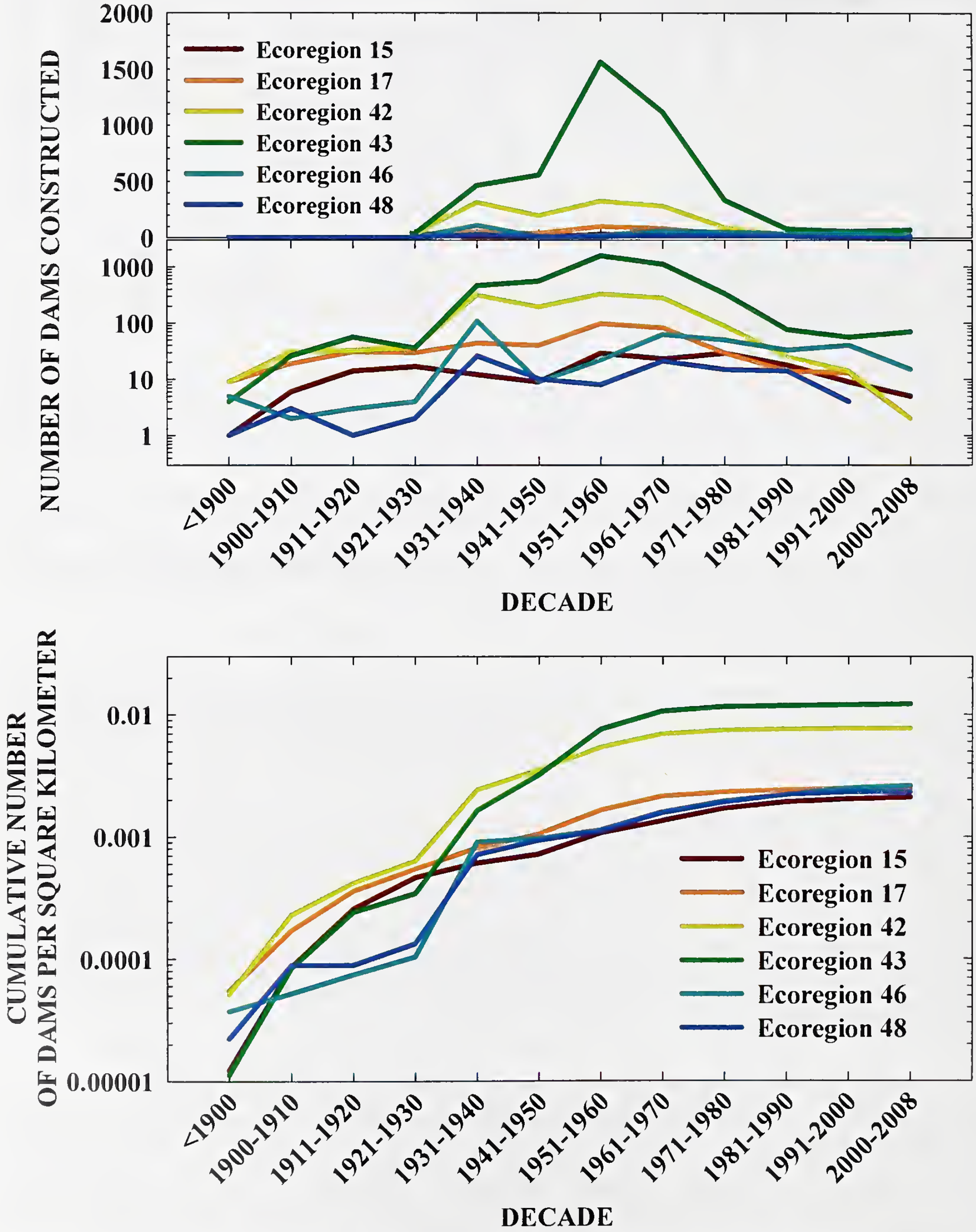

Figure 45 – Decadal trends in the number of dams constructed in each ecoregions (top), and the cumulative number of dams per unit drainage area (bottom).

5.10 Ecological Analysis for the Northwestern Great Plains, Ecoregion 43

The basic approach to the ecological analysis was two-fold. First, analyses were conducted to examine whether relations existed among fish-functional traits and sediment metrics independent of the channel stability classification. The second approach was to test whether differences between stable and unstable channels could be identified among the functional traits.

Table 42 – Functional Traits and codes used to describe them throughout this study.

Abbreviation	Functional Trait
Rearing Habitat Preference	
HABDW	Openwater, deep areas, pools
HABSW	Openwater, shallow areas, backwaters
HABPOOL	Pool, small channels, relatively deep, slow waters
HABRIF	Riffle, small channels, shallow, fast waters
Feeding Trophic Guild	
TRGEN	Generalist feeder: consumes more than 3 different live food items
TRHERB	Hebivore: consumes plant materials including algae and macrophytes
TROMN	Omnivore: consumes detritus, plant material, insects
TRINSE	Insectivore; consumes insects
TRPISC	Piscivore: consumes fish
Feeding Location Guild	
FEEDB	Bottom: benthic feeder on river/stream bottom
FEEDP	Pelagic: openwater and stream mid-column feeder
FEEDS	Surface: openwater and stream surface feeder
Spawning Behavior (Reproductive) Guild	
SPNGOW	Non-guarder, open substratum spawner, non-adhesive eggs
SPNGOA	Non-guarder, open substratum spawner, adhere eggs to rocks or plants
SPNGNS	Non-guarder, brood hiders, builds nests or redds
SPGADH	Guarder, no nest, adhere eggs on substrate
SPGADH	Guarder, no nest, hides eggs in rock/bed substrate cavities
SPGNE	Guarder, nest builder, no specialized material
SPGNGR	Guarder, nest builder, use clean gravel/pebble
SPGNMD	Guarder, nest builder, use soft mud and/or vegetation

5.10.1 Fish Functional-Traits Composition

The two-way cluster analysis identified three groups of functional traits (x-axis in Figure 46). They were: 1) traits commonly expressed throughout the database species pool (HABSW, HABPOOL, FEEDB, TRINSE, TRGEN, SPNGOW, SPGHO); 2) traits moderately expressed that typically live in larger channels (HABDW, FEEDP, TRPISC, FEEDS, SPGNMD, SPNGNS); and 3) traits more rarely expressed (HABRIF, TROMN, SPNGOA, TRHERB, SPGADH, SPGNE, SPGNGR). Dominance of trait expressions in the species database pool was also observed as a continuum in the dominance curve plot (Figure 47). Bottom feeders (FEEDB) were the most common functional trait expressed, and spawning guarders with "no nest but adhere eggs to material" (SPGADH) were the least common trait expressed in the database species pool. The trend from most to least common was consistent with the three groupings observed in the two-way cluster analysis. Although not all species found in Ecoregion 43 were part of this study's species pool, it can be interpreted that the observed functional-trait composition is indicative of this ecoregion, and generally provides context for assessment of ecological impacts from suspended-sediment stressors.

Based on site occurrences of expressed traits, preferred rearing habitat was dominated by shallow open water rearing in rivers (HABSW, 35%) and stream pool use (HABPOOL, 33%; Figure 48). Stream riffle use (HABRIF) occurred least making up 7% of the total for preferred rearing habitat because only three fish species in the database express this trait (Figure 46). Traits within the feeding tropic guild were dominated by feeding generalist (TRGEN, 35%) and insectivores (TRINSE, 35%). The least dominant traits in this guild included omnivores (TROMN, 14%), piscivores (TRPISC, 11%), and herbivores (TRHERB, 5%). Traits within the feeding location guild were dominated by bottom feeders (FEEDB, 60%), and least by surface feeders (FEEDS, 15%). Traits within the spawning behavior guild were dominated by spawning egg non-guarders for open water both non-adhesive and adhesive eggs (SPNGOW, 43%; SPNGOA, 21%), spawning egg guarders depositing eggs in crevices/holes and gravel nest builders (SPGHO, 17%; SPGNGR, 10%). Overall, non-guarding spawners dominated this guild accounting for 67% of the total trait expressed, compared to 33% for the guarding spawners.

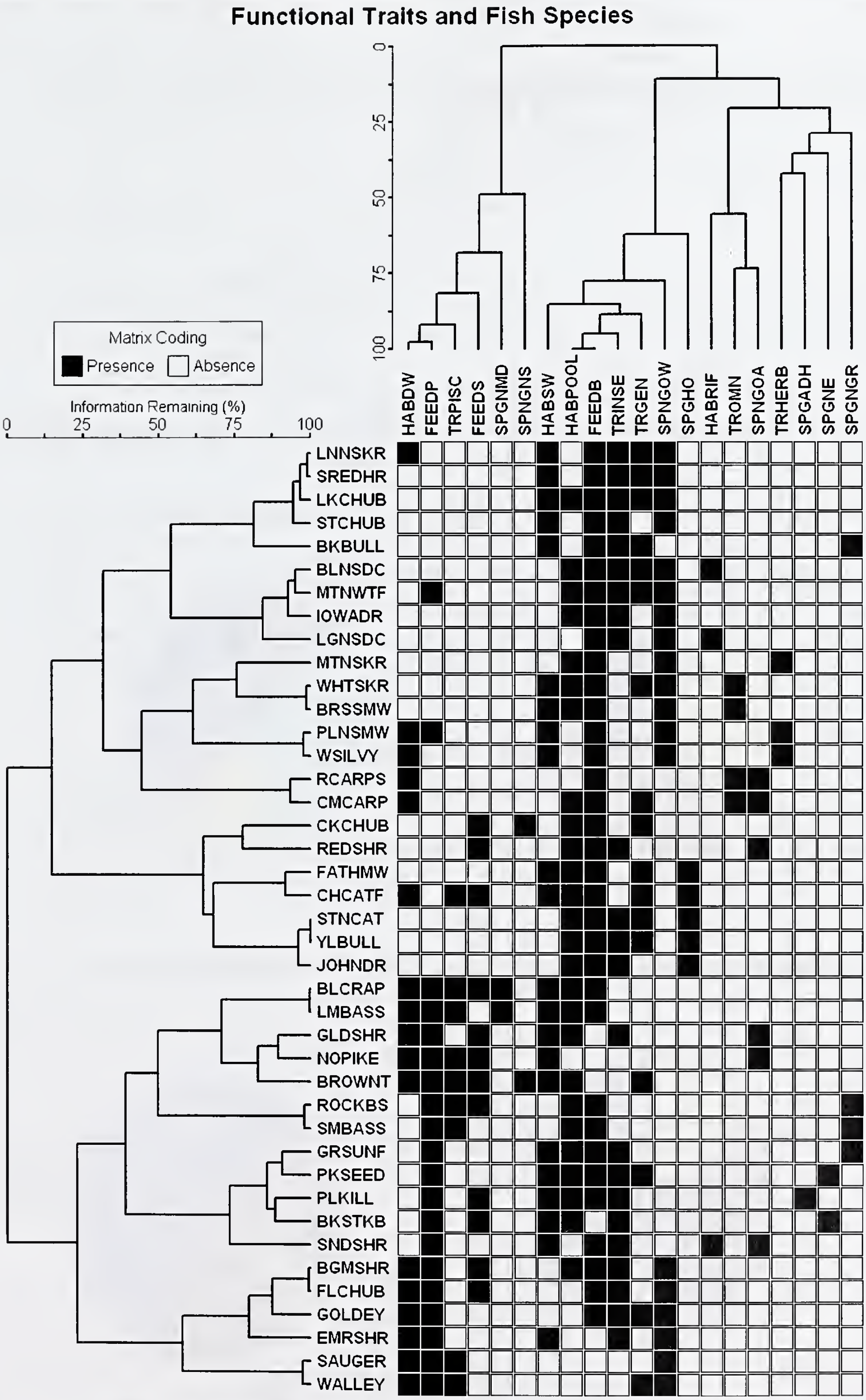

Figure 46 – Relations between functional traits expressed by the species pool in Ecoregion 43. The three main groupings of functional traits are shown on the x-axis. Note: Trait codes (x-axis) are identified in Table 42 and fish species codes (y-axis) are listed in Table 6.

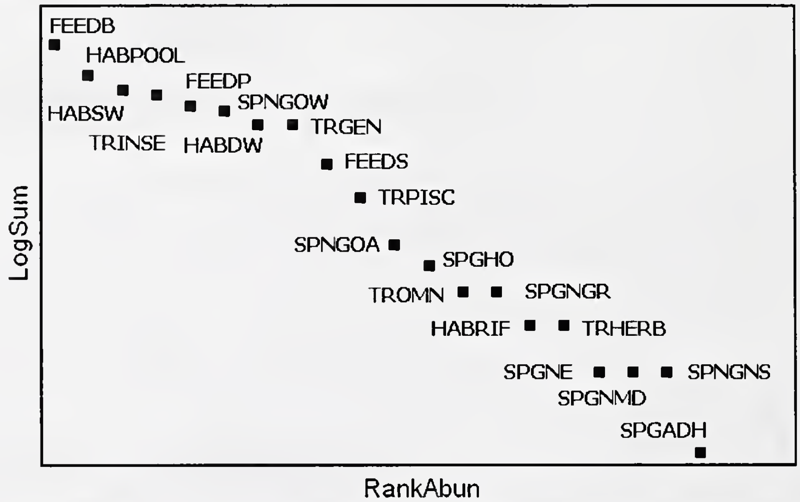

Figure 47 – Dominance curve for functional traits based on species pool compiled in Ecoregion 43. Trait codes can be found in Table 42.

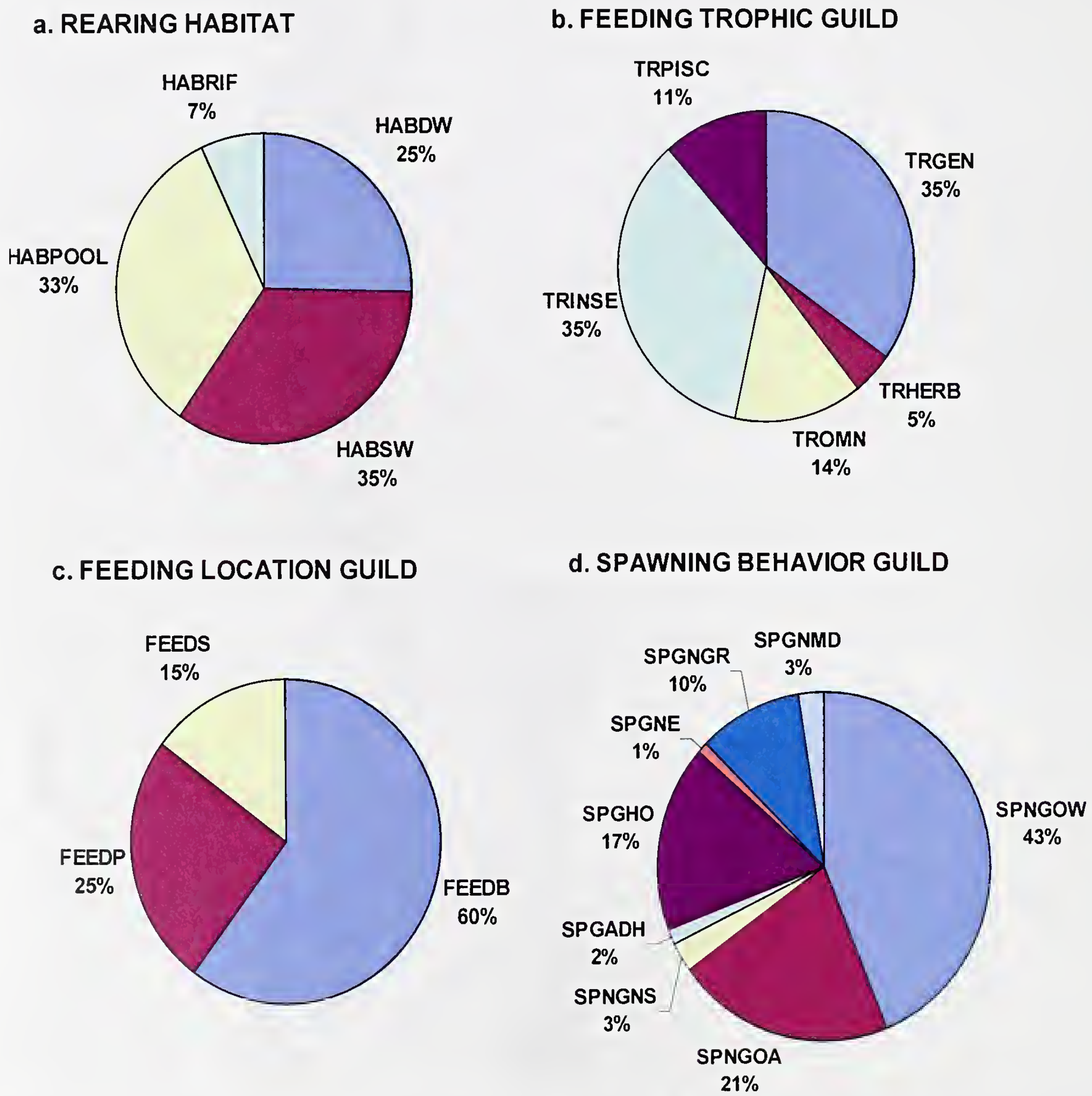

Figure 48 – Functional traits composition based on sum of trait expressions per site, and expressed as percentages by major trait group: a) preferred rearing habitat, b) feeding trophic guild, c) feeding location guild, and d) spawning behavior guild. Trait codes can be found in Table 42.

5.10.2 Correlations among Fish-Functional Traits and Suspended-Sediment Metrics

In general, three patterns were observed from the Pearson correlation analysis, with the following interpretations:

1. Significant correlations across a broad range of percentage of time that a given suspended-sediment concentration was equaled or exceeded (e.g., 95% through 0.01%). This indicates a trait composed of fish species that were influenced by the suspended-sediment gradient across a range of flow conditions. Favorable responses indicated a species group per trait that were tolerant or have adapted to the suspended-sediment gradient, and unfavorable responses indicated species impacted by elevated levels of suspended-sediment.

2. Significant correlations occurred at the upper range of percentage of time a given suspended-sediment concentration was equaled or exceeded (e.g., 95%, 90%). This indicates a trait composed of fish species influenced by suspended-sediment concentration which occurred more often with flows near or slightly above baseflow. Favorable responses indicate species that benefit ecologically from prolonged periods of elevated SSC, and unfavorable responses indicate species that are impacted by this condition.

3. Significant correlations occurred at the lower range of % of time a given suspended-sediment concentration was equaled or exceeded (high concentrations; e.g., 25% through 0.01%). This indicates a trait composed of fish species influenced by high suspended-sediment concentrations that occur less frequently during stormflow events. Unfavorable responses would be expected with these correlations.

Each site has unique suspended-sediment concentration (SSC) values per exceedance frequency, duration (days) and dosage (mg/l-days), and were denoted by specified exceedance frequencies. Significant correlations among traits and site values for SSC frequency, duration, and dosage were interpreted within the context of the three patterns described above, and whether traits appeared to be governed positively or negatively (Table 43). In addition, influences of watershed condition by drainage area, elevation, and suspended-sediment yield (SSY) on correlations with traits were examined to support examination of potential impairments (Table 44). Interpretation of the correlation analysis follows.

Table 43 – Summary of Pearson correlation analyses among fish functional traits and suspended-sediment metrics: a) log-transformed suspended-sediment concentration (mg/l) for different percentages of time in which suspended-sediment was equaled or exceeded; b) log-transformed average number of consecutive days a given suspended-sediment concentration was equaled or exceeded (duration); and c) log-transformed suspended-sediment dosage (mg/l-day) a given suspended-sediment concentration was equaled or exceeded. Per trait and sediment metric correlation, Pearson's correlation coefficients (r) are shown with the significance level in parentheses. Correlations with a significance level above 95% ($p < 0.05$) are shown in cells shaded gray. Trait codes are listed in Table 42.

43a.1) Correlations among functional traits for the habitat guilds and log-transformed suspended-sediment concentration (mg/l) for different percentages of time in which suspended-sediment concentration was equaled or exceeded.

% Exceedance of daily SSC	PREFERRED REARING HABITAT			
	HABDW	HABSW	HABPOOL	HABRIF
99%	-0.007 (0.961)	-0.382 (0.003)	0.045 (0.735)	0.104 (0.437)
95%	0.342 (0.009)	-0.303 (0.021)	-0.357 (0.006)	0.127 (0.343)
90%	0.284 (0.031)	-0.004 (0.975)	-0.282 (0.032)	0.133 (0.321)
75%	0.403 (0.002)	-0.167 (0.209)	-0.422 (0.001)	0.063 (0.636)
50%	0.423 (0.001)	-0.110 (0.409)	-0.454 (<0.001)	0.078 (0.560)
25%	0.423 (0.001)	-0.114 (0.395)	-0.585 (<0.001)	0.164 (0.219)
10%	0.406 (0.002)	-0.145 (0.279)	-0.602 (<0.001)	0.187 (0.159)
5%	0.390 (0.002)	-0.159 (0.233)	-0.605 (<0.001)	0.206 (0.121)
1%	0.352 (0.007)	-0.167 (0.210)	-0.598 (<0.001)	0.237 (0.074)
0.1%	0.309 (0.018)	-0.167 (0.212)	-0.579 (<0.001)	0.265 (0.044)
0.01%	0.284 (0.031)	-0.178 (0.180)	-0.570 (<0.001)	0.287 (0.029)

43a.2) Correlations among functional traits for the feeding guilds and log-transformed suspended-sediment concentration (mg/L) for different percentages of time in which suspended-sediment concentration was equaled or exceeded.

% Exceedance of daily SSC	FEEDING TROPHIC AND LOCATION GUILDS							
	TRGEN	TRHERB	TROMN	TRINSE	TRPISC	FEEDB	FEEDP	FEEDS
99%	-0.096 (0.474)	-0.059 (0.232)	-0.151 (0.258)	0.159 (0.234)	0.097 (0.470)	-0.015 (0.912)	0.281 (0.033)	0.052 (0.700)
95%	-0.448 (<0.001)	0.181 (0.174)	-0.284 (0.038)	0.253 (0.055)	0.093 (0.488)	0.018 (0.891)	0.342 (0.009)	0.331 (0.011)
90%	-0.388 (0.003)	0.145 (0.276)	-0.284 (0.031)	0.249 (0.060)	0.053 (0.695)	0.118 (0.376)	0.313 (0.017)	0.078 (0.182)
75%	-0.330 (0.011)	0.144 (0.282)	-0.284 (0.031)	0.197 (0.138)	0.123 (0.360)	0.082 (0.542)	0.372 (0.004)	0.091 (0.498)
50%	-0.295 (0.024)	0.280 (0.033)	-0.301 (0.022)	0.121 (0.367)	0.026 (0.849)	0.208 (0.117)	0.330 (0.011)	0.142 (0.288)
25%	-0.396 (0.002)	0.414 (0.001)	-0.348 (0.007)	0.193 (0.146)	-0.172 (0.197)	0.342 (0.009)	0.335 (0.010)	0.213 (0.109)
10%	-0.403 (0.002)	0.462 (<0.001)	-0.342 (0.009)	0.192 (0.148)	-0.227 (0.086)	0.378 (0.003)	0.311 (0.018)	0.196 (0.140)
5%	-0.408 (0.001)	0.476 (<0.001)	-0.344 (0.008)	0.204 (0.125)	-0.252 (0.057)	0.388 (0.003)	0.306 (0.019)	0.202 (0.129)
1%	-0.416 (0.001)	0.492 (<0.001)	-0.336 (0.010)	0.214 (0.106)	-0.294 (0.025)	0.390 (0.002)	0.307 (0.019)	0.210 (0.113)
0.1%	-0.414 (0.001)	0.498 (<0.001)	-0.310 (0.018)	0.205 (0.123)	-0.329 (0.012)	0.405 (0.002)	0.274 (0.037)	0.184 (0.166)
0.01%	-0.413 (0.001)	0.497 (<0.001)	-0.289 (0.028)	0.211 (0.112)	-0.350 (0.007)	0.418 (0.001)	0.257 (0.050)	0.166 (0.214)

43a.3) Correlations among functional traits for the spawning behavior guilds and log-transformed suspended-sediment concentration (mg/L) for different percentages of time in which suspended-sediment concentration was equaled or exceeded.

% Exceedance of daily SSC	SPAWNING BEHAVIOR GUILD							
	SPNGOW	SPNGOA	SPNGNS	SPGADH	SPGHO	SPGNE	SPGNGR	SPGNMD
99%	-0.071 (0.599)	-0.062 (0.644)	-0.144 (0.280)	0.261 (0.048)	0.080 (0.551)	-0.026 (0.846)	-0.023 (0.862)	0.152 (0.256)
95%	0.319 (0.015)	-0.021 (0.876)	-0.222 (0.095)	0.082 (0.539)	-0.094 (0.481)	-0.168 (0.206)	-0.299 (0.023)	-0.006 (0.967)
90%	0.224 (0.091)	-0.004 (0.975)	-0.229 (0.084)	0.054 (0.687)	0.025 (0.853)	-0.263 (0.046)	-0.279 (0.034)	0.114 (0.394)
75%	0.206 (0.120)	0.113 (0.398)	-0.473 (<0.001)	-0.054 (0.689)	0.097 (0.470)	-0.347 (0.008)	-0.181 (0.175)	0.031 (0.817)
50%	0.142 (0.288)	0.144 (0.282)	-0.386 (0.003)	0.032 (0.809)	0.145 (0.278)	-0.354 (0.006)	-0.177 (0.184)	-0.070 (0.601)
25%	0.155 (0.247)	0.154 (0.248)	-0.319 (0.015)	0.200 (0.132)	0.031 (0.818)	-0.266 (0.043)	-0.191 (0.150)	-0.180 (0.176)
10%	0.175 (0.189)	0.121 (0.364)	-0.291 (0.027)	0.226 (0.088)	0.003 (0.984)	-0.241 (0.068)	-0.190 (0.154)	-0.221 (0.096)
5%	0.180 (0.176)	0.117 (0.380)	-0.282 (0.032)	0.247 (0.062)	-0.008 (0.955)	-0.231 (0.081)	-0.194 (0.144)	-0.239 (0.071)
1%	0.178 (0.181)	0.133 (0.320)	-0.271 (0.040)	0.288 (0.028)	-0.023 (0.862)	-0.224 (0.091)	-0.200 (0.132)	-0.267 (0.043)
0.1%	0.172 (0.196)	0.144 (0.281)	-0.258 (0.051)	0.293 (0.026)	-0.030 (0.825)	-0.225 (0.090)	-0.194 (0.145)	-0.286 (0.030)
0.01%	0.185 (0.165)	0.141 (0.290)	-0.271 (0.040)	0.282 (0.032)	-0.036 (0.790)	-0.217 (0.101)	-0.192 (0.149)	-0.296 (0.024)

43b.1) Correlations among functional traits for the habitat guilds and log-transformed average number of consecutive days a given suspended-sediment concentration (mg/L) was equaled or exceeded.

% Exceedance of daily SSC	PREFERRED REARING HABITAT			
	HABDW	HABSW	HABPOOL	HABRIF
99%	0.250 (0.058)	-0.293 (0.026)	-0.175 (0.188)	-0.033 (0.807)
95%	0.269 (0.042)	-0.093 (0.487)	-0.225 (0.090)	-0.099 (0.459)
90%	0.259 (0.050)	0.038 (0.776)	-0.187 (0.160)	-0.202 (0.129)
75%	0.136 (0.310)	0.217 (0.102)	-0.002 (0.985)	-0.323 (0.013)
50%	-0.102 (0.448)	0.158 (0.236)	0.173 (0.195)	-0.312 (0.017)
25%	-0.147 (0.271)	0.025 (0.853)	0.336 (0.010)	-0.297 (0.024)
10%	-0.152 (0.254)	0.046 (0.732)	0.350 (0.007)	-0.262 (0.047)
5%	-0.149 (0.264)	-0.007 (0.956)	0.331 (0.011)	-0.231 (0.081)
1%	-0.051 (0.704)	0.029 (0.829)	0.164 (0.218)	-0.114 (0.394)
0.1%	0.036 (0.787)	-0.031 (0.818)	0.013 (0.925)	-0.091 (0.498)
0.01%	0.103 (0.443)	-0.116 (0.387)	-0.082 (0.542)	-0.038 (0.777)

43b.2) Correlations among functional traits for the feeding guilds and log-transformed average number of consecutive days a given suspended-sediment concentration (mg/L) was equaled or exceeded.

% Exceedance of daily SSC	FEEDING TROPHIC AND LOCATION GUILDS							
	TRGEN	TRHERB	TROMN	TRINSE	TRPISC	FEEDB	FEEDP	FEEDS
99%	-0.236 (0.075)	-0.003 (0.982)	-0.070 (0.599)	0.115 (0.390)	0.330 (0.011)	-0.213 (0.109)	0.172 (0.196)	-0.080 (0.553)
95%	-0.103 (0.441)	-0.014 (0.919)	0.004 (0.979)	0.027 (0.839)	0.333 (0.011)	-0.182 (0.172)	0.080 (0.551)	-0.216 (0.103)
90%	0.046 (0.734)	-0.075 (0.578)	0.124 (0.354)	-0.090 (0.501)	0.340 (0.009)	-0.187 (0.159)	-0.010 (0.939)	-0.299 (0.022)
75%	0.235 (0.076)	-0.091 (0.498)	0.194 (0.144)	-0.284 (0.031)	0.270 (0.040)	-0.120 (0.368)	-0.094 (0.481)	-0.408 (0.001)
50%	0.325 (0.013)	-0.265 (0.044)	0.255 (0.053)	-0.191 (0.150)	0.183 (0.169)	-0.225 (0.089)	-0.188 (0.157)	-0.411 (0.001)
25%	0.338 (0.009)	-0.265 (0.044)	0.222 (0.094)	-0.204 (0.125)	0.287 (0.029)	-0.229 (0.084)	-0.255 (0.053)	-0.395 (0.002)
10%	0.336 (0.010)	-0.417 (0.001)	0.236 (0.074)	-0.098 (0.465)	0.332 (0.011)	-0.142 (0.289)	-0.285 (0.030)	-0.307 (0.019)
5%	0.266 (0.043)	-0.431 (0.001)	0.248 (0.061)	-0.065 (0.626)	0.329 (0.012)	-0.167 (0.210)	-0.289 (0.028)	-0.236 (0.075)
1%	0.298 (0.023)	-0.262 (0.047)	0.134 (0.317)	-0.037 (0.782)	0.228 (0.085)	-0.033 (0.806)	-0.248 (0.061)	-0.246 (0.062)
0.1%	0.082 (0.539)	-0.027 (0.841)	0.151 (0.259)	-0.032 (0.813)	-0.028 (0.834)	-0.001 (0.992)	-0.091 (0.497)	-0.281 (0.033)
0.01%	0.026 (0.846)	-0.016 (0.903)	-0.040 (0.767)	0.051 (0.704)	0.023 (0.864)	0.058 (0.664)	-0.028 (0.834)	-0.020 (0.881)

43b.3) Correlations among functional traits for the spawning behavior guilds and log-transformed average number of consecutive days for a given suspended-sediment concentration (mg/L) was equaled or exceeded.

% Exceedance of daily SSC	SPAWNING BEHAVIOR GUILD							
	SPNGOW	SPNGOA	SPNGNS	SPGADH	SPGHO	SPGNE	SPGNGR	SPGNMD
99%	0.361 (0.005)	-0.117 (0.382)	-0.243 (0.067)	-0.338 (0.009)	-0.048 (0.721)	-0.255 (0.053)	-0.189 (0.155)	0.168 (0.207)
95%	0.290 (0.027)	-0.084 (0.529)	-0.290 (0.027)	-0.413 (0.001)	-0.081 (0.546)	-0.285 (0.030)	-0.053 (0.695)	0.138 (0.301)
90%	0.186 (0.163)	-0.094 (0.481)	-0.294 (0.025)	-0.417 (0.001)	-0.015 (0.909)	-0.179 (0.178)	0.078 (0.561)	0.148 (0.267)
75%	-0.041 (0.761)	-0.279 (0.034)	-0.095 (0.476)	-0.310 (0.021)	0.002 (0.989)	0.068 (0.610)	0.319 (0.015)	0.163 (0.222)
50%	-0.093 (0.486)	-0.257 (0.052)	0.144 (0.282)	-0.310 (0.018)	-0.098 (0.466)	0.333 (0.011)	0.370 (0.004)	0.093 (0.487)
25%	-0.007 (0.958)	-0.374 (0.006)	0.149 (0.264)	-0.338 (0.010)	0.026 (0.844)	0.194 (0.145)	0.183 (0.168)	0.208 (0.117)
10%	-0.082 (0.539)	-0.204 (0.125)	0.009 (0.947)	-0.339 (0.009)	0.065 (0.629)	0.201 (0.130)	0.207 (0.119)	0.262 (0.047)
5%	-0.063 (0.638)	-0.117 (0.382)	-0.052 (0.696)	-0.334 (0.010)	0.110 (0.413)	0.163 (0.222)	0.133 (0.319)	0.199 (0.135)
1%	0.003 (0.980)	-0.207 (0.120)	-0.036 (0.787)	-0.312 (0.017)	0.137 (0.304)	0.043 (0.749)	0.137 (0.304)	0.077 (0.565)
0.1%	0.153 (0.250)	-0.126 (0.345)	-0.101 (0.451)	-0.109 (0.414)	0.116 (0.387)	-0.131 (0.327)	-0.027 (0.842)	-0.199 (0.135)
0.01%	0.119 (0.372)	-0.206 (0.121)	-0.099 (0.461)	-0.156 (0.244)	0.120 (0.370)	0.102 (0.448)	-0.073 (0.589)	0.038 (0.777)

43c.1) Correlations among functional traits for the habitat guilds and log-transformed suspended-sediment dosage (mg/L-day) for a given suspended-sediment concentration (mg/L) was equaled or exceeded.

% Exceedance of daily SSC	PREFERRED REARING HABITAT			
	HABDW	HABSW	HABPOOL	HABRIF
99%	-0.019 (0.886)	-0.267 (0.043)	0.082 (0.543)	0.073 (0.588)
95%	0.336 (0.014)	-0.460 (<0.001)	-0.323 (0.013)	0.118 (0.379)
90%	0.246 (0.063)	-0.359 (0.006)	-0.211 (0.112)	0.124 (0.355)
75%	0.386 (0.003)	-0.156 (0.243)	-0.347 (0.008)	-0.008 (0.951)
50%	0.400 (0.002)	-0.089 (0.508)	-0.357 (0.006)	-0.012 (0.930)
25%	0.434 (0.001)	-0.120 (0.368)	-0.567 (<0.001)	0.107 (0.422)
10%	0.413 (0.001)	-0.149 (0.264)	-0.580 (<0.001)	0.143 (0.285)
5%	0.393 (0.002)	-0.177 (0.183)	-0.587 (<0.001)	0.171 (0.200)
1%	0.356 (0.006)	-0.168 (0.207)	-0.590 (<0.001)	0.223 (0.092)
0.1%	0.312 (0.017)	-0.170 (0.202)	-0.571 (<0.001)	0.247 (0.062)
0.01%	0.059 (0.658)	-0.037 (0.784)	-0.416 (0.001)	0.331 (0.011)

43c.2) Correlations among functional traits for the feeding guilds and log-transformed suspended-sediment dosage (mg/L-day) for a given suspended-sediment concentration was equaled or exceeded.

% Exceedance of daily SSC	FEEDING TROPHIC AND LOCATION GUILDS							
	TRGEN	TRHERB	TROMN	TRINSE	TRPISC	FEEDB	FEEDP	FEEDS
99%	-0.051 (0.706)	-0.165 (0.215)	-0.114 (0.394)	0.119 (0.373)	-0.165 (0.216)	-0.081 (0.544)	0.232 (0.080)	0.024 (0.861)
95%	-0.430 (0.001)	0.169 (0.205)	-0.226 (0.089)	0.232 (0.080)	0.152 (0.253)	-0.029 (0.831)	0.261 (0.048)	0.273 (0.038)
90%	-0.346 (0.008)	0.091 (0.498)	-0.228 (0.085)	0.238 (0.072)	0.115 (0.391)	0.085 (0.527)	0.235 (0.075)	0.101 (0.449)
75%	-0.234 (0.077)	0.053 (0.695)	-0.186 (0.162)	0.138 (0.303)	0.229 (0.084)	0.001 (0.997)	0.322 (0.014)	-0.062 (0.642)
50%	-0.175 (0.188)	0.195 (0.141)	-0.213 (0.108)	0.033 (0.803)	0.125 (0.352)	0.125 (0.349)	0.274 (0.037)	0.015 (0.910)
25%	-0.356 (0.006)	0.394 (0.002)	-0.331 (0.011)	0.164 (0.220)	-0.119 (0.375)	0.323 (0.013)	0.309 (0.018)	0.137 (0.305)
10%	-0.364 (0.005)	0.409 (0.001)	-0.320 (0.014)	0.189 (0.156)	-0.169 (0.203)	0.384 (0.003)	0.274 (0.037)	0.141 (0.290)
5%	-0.385 (0.003)	0.420 (0.001)	-0.320 (0.014)	0.209 (0.116)	-0.198 (0.137)	0.387 (0.003)	0.267 (0.042)	0.165 (0.216)
1%	-0.372 (0.004)	0.459 (<0.001)	-0.323 (0.013)	0.216 (0.103)	-0.260 (0.049)	0.400 (0.002)	0.269 (0.041)	0.169 (0.205)
0.1%	-0.396 (0.002)	0.489 (<0.001)	-0.281 (0.033)	0.197 (0.138)	-0.331 (0.011)	0.401 (0.002)	0.256 (0.050)	0.135 (0.314)
0.01%	-0.349 (0.007)	0.389 (0.003)	-0.316 (0.016)	0.296 (0.024)	-0.390 (0.002)	0.413 (0.001)	0.201 (0.130)	0.104 (0.437)

43c.3) Correlations among functional traits for the spawning behavior guilds and log-transformed suspended-sediment dosage (mg/L-day) for a given suspended-sediment concentration was equaled or exceeded.

% Exceedance of daily SSC	SPAWNING BEHAVIOR GUILD							
	SPNGOW	SPNGOA	SPNGNS	SPGADH	SPGHO	SPGNE	SPGNGR	SPGNMD
99%	-0.008 (0.952)	-0.140 (0.295)	-0.088 (0.511)	0.161 (0.228)	0.057 (0.670)	0.015 (0.912)	-0.053 (0.693)	0.180 (0.176)
95%	0.408 (0.001)	-0.126 (0.348)	-0.174 (0.191)	-0.018 (0.893)	-0.130 (0.331)	-0.155 (0.245)	-0.328 (0.012)	0.022 (0.867)
90%	0.272 (0.039)	-0.102 (0.446)	-0.201 (0.131)	-0.034 (0.800)	0.033 (0.808)	-0.259 (0.050)	-0.293 (0.026)	0.179 (0.179)
75%	0.225 (0.089)	-0.041 (0.760)	-0.530 (<0.001)	-0.199 (0.135)	0.118 (0.378)	-0.363 (0.005)	-0.108 (0.418)	0.100 (0.457)
50%	0.123 (0.357)	0.086 (0.519)	-0.382 (0.003)	-0.101 (0.450)	0.180 (0.177)	-0.335 (0.010)	-0.100 (0.455)	-0.022 (0.868)
25%	0.170 (0.201)	0.082 (0.541)	-0.318 (0.015)	0.138 (0.015)	0.041 (0.758)	-0.248 (0.061)	-0.167 (0.211)	-0.148 (0.267)
10%	0.173 (0.193)	0.084 (0.530)	-0.321 (0.014)	0.167 (0.211)	0.019 (0.886)	-0.217 (0.101)	-0.159 (0.232)	-0.180 (0.177)
5%	0.183 (0.169)	0.101 (0.450)	-0.324 (0.013)	0.191 (0.151)	0.018 (0.892)	-0.215 (0.105)	-0.182 (0.172)	-0.215 (0.105)
1%	0.186 (0.161)	0.096 (0.473)	-0.290 (0.027)	0.236 (0.074)	0.004 (0.997)	-0.225 (0.090)	-0.138 (0.310)	-0.263 (0.046)
0.1%	0.197 (0.139)	0.121 (0.365)	-0.273 (0.038)	0.271 (0.040)	-0.009 (0.944)	-0.245 (0.063)	-0.196 (0.139)	-0.317 (0.015)
0.01%	0.130 (0.330)	0.046 (0.732)	-0.219 (0.099)	0.262 (0.047)	-0.001 (0.999)	-0.160 (0.229)	-0.123 (0.359)	-0.229 (0.083)

Table 44 – Summary of Pearson correlation analyses among fish-functional traits environmental gradients: drainage area, elevation, and log-transformed mean annual suspended-sediment yield (SSY). Note: Trait codes are listed in Table 42.

FUNCTIONAL TRAITS	Drainage Area		Elevation		Log (SSY)	
	p	r	p	r	p	r
Preferred Rearing Habitat						
HABDW	0.012	0.337	0.127	-0.212	0.008	0.347
HABSW	0.191	-0.179	0.986	0.002	0.019	-0.310
HABPOOL	0.006	-0.366	0.690	-0.056	<0.001	-0.574
HABRIF	0.728	-0.048	0.002	0.425	0.070	0.242
Trophic Feeding Guild						
TRGEN	0.221	-0.168	0.625	-0.069	<0.001	-0.447
TRHERB	0.304	0.141	0.077	0.245	<0.001	0.529
TROMN	0.233	-0.163	0.022	-0.315	0.007	-0.353
TRINSE	0.141	0.201	0.001	0.454	0.168	0.0185
TRPISC	0.778	-0.039	0.027	-0.305	0.217	-0.166
Feeding Location Guild						
FEEDB	0.274	0.150	0.175	0.189	0.042	0.271
FEEDP	0.045	0.271	0.057	0.263	0.039	0.275
FEEDS	0.630	-0.066	0.273	-0.153	0.069	0.243
Spawning Behavior Guild						
SPNGOW	0.169	0.188	0.108	0.223	0.006	0.361
SPNGOA	0.240	-0.161	0.051	-0.270	0.539	-0.083
SPNGNS	0.173	-0.186	0.276	0.153	0.265	-0.150
SPGADH	0.456	0.103	0.327	0.137	0.248	0.155
SPGHO	0.978	-0.004	0.030	-0.298	0.220	-0.165
SPGNE	0.490	0.095	0.968	-0.006	0.216	-0.166
SPGNGR	0.237	-0.162	0.857	0.025	0.040	-0.272
SPGMD	0.809	-0.033	0.337	-0.135	0.261	-0.151

Two functional traits HABDW and FEEDP were found to be positively correlated across a range of SSC values based on the percentage of time a given SSC was equaled or exceeded from 95% through 0.01% (Table 43). Duration was not as strongly correlated with SSC as frequency and dosage. Both frequency and dosage traits were significantly corrected with drainage area and log mean, annual suspended-sediment yield (SSY), where per site, larger basins and greater SSY correlated with increased occurrences of traits (Table 44). This correlation indicated species grouped by these traits were found more often in larger channels and likely have adapted to the sediment gradient. Species and traits also clustered together as shown in Figure 46. These commonly expressed traits comprise 25% of their trait guild (Figure 48).

HABPOOL negatively correlated across a range of SSC values based on percentage of time a given SSC was equaled or exceeded from 95% through 0.01% for frequency and dosage (Table 43a.1 and 43c.1). HABPOOL duration correlated with SSC frequencies 25%, 10%, and 5% representing SSC values at moderate stormflow levels, and not the less frequent, high concentration events. HABPOOL was significantly correlated with drainage area and log SSY, where per site smaller watersheds and lower SSY overall correlated with increased trait occurrences (Table 44). Significant correlations indicated that stream and small-river species that occupy pool habitats appeared to be negatively impacted by slight changes in SSC regimes, beginning at the 95% exceedance level for frequency and dosage. Impairment thresholds can be inferred from these results relying on an average among the sites below a designated drainage area size (Table 45). For example, thresholds for watersheds < 3000 km^2 could include: 1) < 34 mg/l for the SSC 95% exceedance level, 2) < 2668 mg/l-day dosage based on the 95% exceedance SSC level; and 3) no longer than 14 days for SSC 517 mg/l or greater based on duration at the SSC 25% exceedance level.

TRGEN and TROMN were found to be negatively correlated across a range of SSC values based on the percentage of time a given SSC was equaled or exceeded from 95% through 0.01% for frequency, and from 25% to 0.01% for dosage levels (Table 43a.2 and 43c.2). In addition, TRGEN and TROMN were found to be negatively correlated with log SSY, but not drainage area (Table 44). TROMN was significantly correlated with elevation, in which trait occurrences increased in lower-elevation watersheds. Assuming a range for lower elevations as < 800 m above mean sea level, a potential impairment threshold using TROMN could be < 13,500 mg/l-day dosage based on the 25% exceedance SSC level (Table 45).

FEEDS and SPNGOW were found to be positively correlated at the upper range of SSC value based on the percentage of time a given SSC was equaled or exceeded for 95% (Table 43a.2 and 43a.3). In addition, SPNGOW was positively correlated with log SSY (Table 44). They did not correlate with drainage area or elevation. This trait was the most common within the spawning behavior guild accounting for 43% of the species.

HABSW, TRGEN, and SPGNGR were found to be negatively correlated at the upper range of SSC values based on the percentage of time a given SSC was equaled or exceeded generally for 90% and 95% dosage levels (Table 43). They were negatively

correlated with log SSY (Table 44). TRGEN was negatively correlated from 95% through 0.01% for SSC exceedance frequencies, a broad range of % exceedances for this sediment metric compared to the other two traits. Durations were correlated between SSC frequencies 50% through 1% for TRGEN, and 75% and 50% for SPGNGR. As with species associated with the HABPOOL trait, fish associated with HABSW, TRGEN, and SPGNGR traits may be similarly sensitive to slight increases in elevated SSC. However, these traits were not found to be dependent on watershed drainage area. Impairment thresholds can be inferred from these results relying on an average among all 58 sites (Table 45). For example, thresholds could include: 1) < 19 mg/l for the SSC 95% exceedance level, 2) < 1500 mg/l-day dosage based on the SSC 95% exceedance level; and 3) no longer than 23 days for SSC 83.4 mg/l or greater based on duration at the SSC 50% exceedance level.

Table 45 – Summary of potential thresholds for biological impairment due to suspended-sediment from ecological analysis using Pearson correlations among fish functional traits and sediment metrics. Note: Concentrations have been rounded to three significant figures; Trait codes are listed in Table 42.

FUNCTIONAL TRAITS	**Frequency:** SSC (mg/l) by % of time a given SSC is equaled or exceeded	**Duration:** Average number of days a given SSC is equaled or exceeded	**Dosage:** SSC x duration (mg/l-day) for a % of time a given SSC is equaled or exceeded
HABPOOL (< 3000 km^2 drainage area)	< 34 mg/l for the SSC 95% exceedance level	< 14 days for SSC ≥ 517 mg/l based on a SSC 25% exceedance level	< 2,670 mg/l-day dosage based on the SSC 95% exceedance level
TROMN (< 800 m MSL elevation)	---	---	< 13,500 mg/l-day dosage based on the SSC 25% exceedance level
TRPISC (< 800 m MSL elevation)	< 4,870 mg/l for the SSC 1% exceedance level	---	< 12,200 mg/l-day dosage based on the SSC 1% exceedance level
TRPISC (> 800 m MSL elevation)	< 7,200 mg/l for the SSC 1% exceedance level	---	< 15,600 mg/l-day dosage based on the SSC 1% exceedance level
HABSW TRGEN SPGNGR	< 19 mg/l for the SSC 95% exceedance level	< 23 days for SSC ≥ 83.4 mg/l based on a SSC 50% exceedance level	< 1,500 mg/l-day dosage based on the SSC 95% exceedance level
SPGNE	< 33 mg/l for the SSC 90% exceedance level	---	2260 mg/l-day for the SSC 90% exceedance level
SPGADH (> 800 m MSL elevation)	---	< 41 days for SSC ≥ 391 mg/l based on a SSC 75% exceedance level	---
SPNGNS	< 55 mg/l for the SSC 75% exceedance level	---	< 2, 430 mg/l-day dosage based on the SSC 75% exceedance level
SPGMD	< 617 mg/l for the SSC 1% exceedance level	---	< 3,070 mg/l-day dosage based on the SSC 1% exceedance level

SPGNE was also found to be negatively correlated at the upper range of SSC values based on the percentage of time a given SSC is equaled or exceeded generally, but for 90% through 25% SSC frequency levels and 90% through 50% dosage levels (Table 43a.3 and 43c.3). SPGNE was not correlated with log SSY (Table 44). Potential thresholds based on the SPGNE trait and SSC 90% exceedance levels for frequency and dosage were 33 mg/l and 2260 mg/l-day, respectively (Table 45). SPGNE is a rare trait only comprising 1% of the spawning behavior guild. It would only be relevant, therefore, in selected watersheds where this trait may be more dominantly expressed by species in the fish community.

TRHERB and FEEDB were found to be positively correlated at the lower range of SSC values based on the percentage of time a given SSC is equaled or exceeded for a general range from 25% to 0.01% for frequency and dosage (Table 43). Increased TRHERB trait occurrences per site correlated with shorter durations for SSC frequencies between 50% and 1%. FEEDB was not correlated at any duration level. FEEDB traits were, however, positively correlated with log SSY (Table 44). Fish species grouped by TRHERB and FEEDB appear to be tolerant and may benefit from elevated suspended-sediment levels.

HABRIF, TRINSE, and SPGADH were found to be positively correlated at the lower percentages of time a given SSC is equaled or exceeded (high concentrations) for a general range from 1% to 0.01% for frequency and dosage, except SPGADH ranged from 10% to 0.01% for frequency (Table 43a.2 and 43c.2). Only HABRIF correlated positively with log SSY, none were correlated with drainage area, and all three were correlated positively with elevation (Table 44). Increased HABRIF trait occurrences per site correlated with shorter durations for SSC frequencies between 75% and 10%. Increased SPGADH trait occurrences per site correlated with shorter duration for SSC frequencies between 99% and 1%. Ecologically, results from these correlations are difficult to explain because negative correlations would have been expected with sediment metrics. These traits were correlated with elevation and not drainage area. It cannot be assumed, therefore, that these are traits commonly found in small, high elevation headwaters. Rather, it is likely that these traits are specific to a Level IV ecoregion scale, and this analysis is limited by the fact that these traits are rare among each guild class (Figure 48). A negative correlation was observed for dose and SPGADH ($p = 0.135$), and SPDADH was negatively correlated for duration of SSC frequencies. One potential impairment threshold, recognizing the limitations of this dataset could be no longer than 41.4 days for SSC 391 mg/l or greater based on duration at the SSC 75% exceedance level, for watersheds above 800 m in elevation (Table 45).

TRPISC, SPNGNS, and SPGMD were found to be negatively correlated at the lower range of SSC values based on the percentage of time a given SSC is equaled or exceeded for frequency and dosage levels (Table 43). TRPISC and SPGMD ranged from 1% to 0.01% for frequency and dosage while SPNGNS ranged from 75% to 0.01% for frequency and dosage. These traits were not correlated with log SSY. TRPISC was negatively correlated with watershed elevation, and likely due to the centrarchids and salmonids associated with this trait (Table 44, Figure 46). The TRPISC did not correlate with drainage area, although individual piscivore species likely would correlate. For

example, northern pike are commonly found in rivers were rock bass are found more often in streams (Etnier and Starnes, 2001). In general, it appears fish species associated with SPNGNS trait were impacted by moderate frequency events, and TRPISC and SPGMD traits were impacted by less frequent, high SSC events. Impairment thresholds can be inferred from SPNGNS results relying on an average among the 58 sites (Table 45). For example, thresholds could include: 1) < 55 mg/l for the SSC 75% exceedance level, and 2) < 2,430 mg/l-day dosage based on the SSC 75% exceedance level. Similarly, thresholds for SPGMD can be estimated, but based on the SSC 1% exceedance level (Table 45).

In the case of TRPISC and to account for the differences in fish community structure by elevation class, thresholds can be proposed for frequency and dose based on the SSC 1% exceedance level for watersheds above and below 800 m in elevation (Table 45). For example, thresholds for watersheds below 800 m could include: 1) < 4,870 mg/l for the SSC 1% exceedance level, and 2) < 12,200 mg/l-day dosage based on the SSC 1% exceedance level. Thresholds for watersheds below 800 m include: 1) < 7,210 mg/l for the SSC 1% exceedance level, and 2) < 15,600 mg/l-day dosage based on the SSC 1% exceedance level.

5.10.3 Differences in Fish-Functional Traits Based on Channel-Stability Classification

Based on the number of trait occurrences per site and species richness, seven fish functional traits were found to be significantly different between stable and unstable channels at a significance level less than 0.1 (Table 46). They were in order of most to least significant as follow: HABPOOL, TRHERB, HABDW, SPNGOW, SPGNGR, HABSW, and SPGNE. Of the 58 sites used, 23 were determined to be stable, 33 were unstable, and 2 were undetermined (Appendix D). Stable channels were characterized by reduced levels of SSC frequencies, durations, and dosages (Section 5.8).

Stable channels were found to have greater occurrences of HABPOOL and HABSW traits than unstable channels (Table 46). It can be inferred that species associated with these traits were impaired from elevated SSC levels, particularly species in smaller watersheds associated with HABPOOL (Table 45). Impairment could also be a function of habitat quality; thereby stable channels provide better quality pool habitat, and some morphological feature in shallow water areas of rivers. Stable channels appear to benefit "nest building egg guarding spawners" using gravels or general materials for nests (SPGNGR, SPGNE). These two traits in the spawning behavior guild were found to possibly have SSC frequency and dosage thresholds for impairment (Table 45).

Table 46 – Statistical differences between stable and unstable channel classifications among fish functional traits (trait occurrences per site and species richness) for significance levels less than 0.1. Note: trait codes are listed in Table 42.

FUNCTIONAL TRAITS	Means and (standard deviations)		Significance level (p)
	Stable channels	Unstable channels	
HABPOOL	0.629 (0.170)	0.505 (0.167)	0.010
TRHERB	0.040 (0.076)	0.096 (0.082)	0.011
HABDW	0.352 (0.196)	0.466 (0.188)	0.035
SPNGOW	0.389 (0.208)	0.485 (0.143)	0.045
SPGNGR	0.117 (0.124)	0.063 (0.085)	0.070
HABSW	0.638 (0.168)	0.566 (0.025)	0.089
SPGNE	0.016 (0.036)	0.004 (0.014)	0.093

Unstable channels were found to have greater occurrences of HABDW, TRHERB, and SPNGOW traits than stable channels (Table 46). It can be inferred that species associated with these traits are unimpaired or even benefit from elevated SSC levels. These traits were positively correlated with SSC frequencies and dosages (Table 44). Fish species associated with the HABDW trait occur in larger watersheds, and likely are species adapted to elevated SSC levels (Figure 46). Herbivores do not need to see to obtain food items therefore they are likely unimpaired by elevated SSC levels, and could benefits from elevated SSC levels by reducing piscivores predation. "Non-guarding egg dispersing spawners" benefit from generally higher turbidities caused by elevated SSC levels improving recruitment through better egg and fry survival.

Canonical correspondence analysis (CCA) found that channel stability (Stabil) was at least as important as the regional-scale environmental templates, drainage area (DrArea) and elevation (Elev) based on site occurrences of fish-functional traits (Figure 49). This is reflected in the vector length among the three environmental variables. In fact, correlations for Stabil were, in general, slightly higher for eigenanlaysis axes 1 and 2 (0.810, 0.415) than for the environmental variables DrArea (0.683, -0.143) and Elev (0.282, -0.879). The relation between traits and these environmental variables can be observed in Figure 49. For example, HABDW aligns with the direction of the stability vector towards greater unstable channels. In contrast, TRGEN, HABSW, HABPOOL, SPNGNS, and SPGNGR align opposite; the stability vector towards channels that are more stable. SPNGOW and TRHERB traits align with larger watershed drainage areas. TRINSC and FFEDP traits align with higher elevation watersheds.

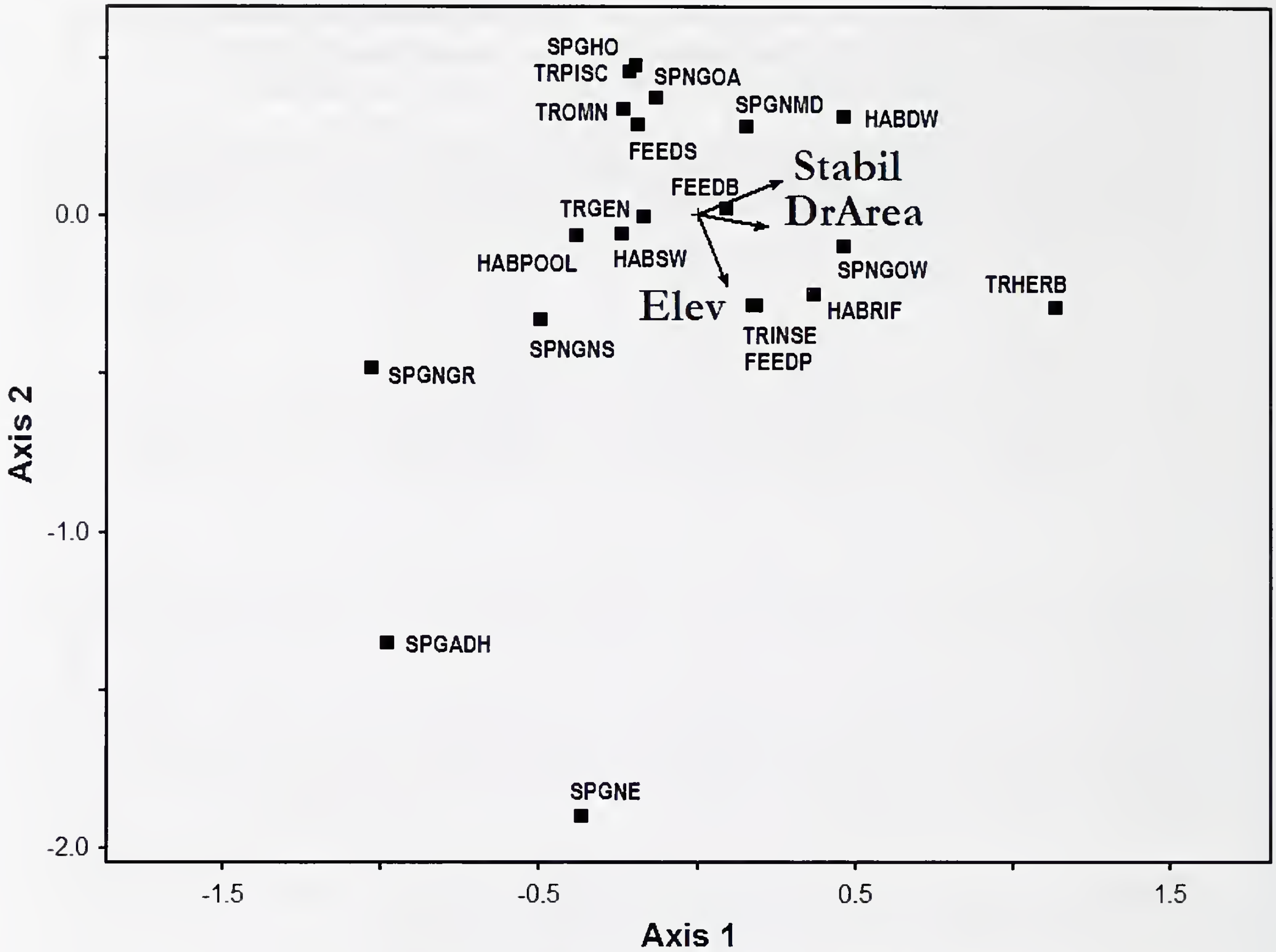

Figure 49 – CCA ordination of fish functional traits by site, and secondary environmental attributes accounting for effects of watershed drainage area (DrArea), elevation (Elev), and channel stability (Stabil). Note: Trait codes are listed in Table 42.

5.10.4 Discussion and Summary of the Functional-Traits Approach for Sediment TMDL Development

A functional traits approach using fish traits grouped by preferred rearing habitat, feeding habits, and spawning behavior provided a means to link elevated SSC levels to biological impairment, where sediment metrics were parameterized by SSC frequencies, durations, and dosages. Biological impairment was based on negatively correlated relations between sediment metrics and functional-trait occurrences per site. This approach differs from others by applying concentration, frequency, and duration measures for suspended sediment, and utilizing traits, rather than fish species assemblages or indices of biotic integrity (Bramblett and Fausch 1991; Bonner and Wilde 2002; Newcombe 2003). To address the issue of natural variability with fish distribution and abundance at an

ecoregion scale, ecological analysis needed to focus on changes in guild composition rather than taxonomic and population-level biological characteristics. This approach allowed for positive relations to be identified as well, where some fish benefit from elevated SSC levels and more turbid waters. This study found three basic patterns of impairment response: 1) elevated SSC levels over a wide range of event frequencies; 2) elevated SSC levels at more frequent, lower SSC events; and 3) elevated SSC levels at less frequent, higher SSC events. Coupled with the differential responses by functional traits, the findings illustrate the complexity of linking excessive in-stream suspended sediment to biological impairments, and why a single, region-wide sediment-metric "threshold" for biological impairment is not appropriate.

Multiple impairment responses based on different fish functional traits were identified. Impairment responses for elevated SSC levels over a wide range of event frequencies, and levels at more frequent, lower SSC events beginning at the 95% recurrence frequency would appear to reflect a general prevailing watershed condition of more turbid waters from suspended sediment. Traits that correlated with sediment metrics for this watershed condition included: 1) preferred pool habitat in streams (HABPOOL); 2) preferred shallow waters in rivers (HABSW); 3) feeding generalist and omnivores (TRGEN, TROMN); 4) a spawning behavior of guarding nests constructed of gravels or general materials (e.g., substrates and vegetation) (SPGNGR, SPGNE). Fish species grouped by these traits would be considered intolerant to slight changes in suspended sediment or turbid waters. Turbidity has been noted as a main stressor to fish in prairie streams (Smith 1979; Matthews 1985). Prolonged periods of elevated SSC and turbidity could limit feeding success for some species that express these traits within the habitat preference and feeding trophic guilds (Rabeni and Smale 1995; DeRobertis *et al.* 2003). In the case of omnivores, the impairment response was dosage dependent and not frequency, supporting this hypothesis. Gravel nest spawners could be impacted by excessive fine sediments associated with elevated SSC levels, which has been shown to occur when fines reduce interstitial oxygen between gravels (Waters 1995). It could also be that gravel substrates were not prevalent for sites that correlated the SPGNGR trait with SSC frequencies and dosages. The correlation, therefore, may have been an indirect measure of habitat and bed-substrate quality in unstable channels.

An impairment response also appeared to occur for elevated SSC levels at less frequent, higher SSC events for fish grouped by traits: 1) piscivores (TRPISC); 2) non-guarding spawners that build nests or redds (SPNGNS), and 3) guarding spawners that build nest in mud substrates (SPGNMD). Elevated SSC levels could have directly affected fish that express these traits, or it could be a surrogate for the more frequent flood events that tend to move bed substrates and potentially degrade physical habitat structure. For piscivores, degraded habitat structure would consist of poor-cover quality and limiting feeding success (Smith 1979). Habitat cover is more important for stream fish found in higher elevation locations, and the TRPISC trait did correlate with elevation in this study. For nest builders, more frequent floods could destroy nests, and limit recruitment. Fausch and Bramblett (1991) describe the importance of floods and droughts on regulating fish distribution and abundance at the local scale, and recognized the importance of habitat quality in fish resilience to these hydrological events.

Beneficial responses from elevated SSC levels occurred for fish grouped by traits: 1) preferred deep-water river habitat (HABDW), 2) surface and pelagic feeders (FEEDS, FEEDP), and 3) non-guarding, open water dispersal spawners (SPNGOW). In general, fish species that express these traits are likely to be tolerant of turbid waters. Ecologically, surface feeders would benefit from higher SSCs that occur for flows near baseflow levels because prey capture is a function of surface movements and not in-stream turbidity, and they would be less prone to predation from piscivores. Fish that spawn by non-adhesive egg dispersal in open waters would also benefit ecologically, because the probability that eggs are preyed upon would be reduced. HABDW and SPNGOW traits were found to be significantly different between stable and unstable channels, suggesting that increased SSC from unstable conditions favor fish species with these traits.

A key utility of a functional traits approach was to propose quantifiable "thresholds" that can be used as TMDL targets, based on loss of some ecological function (i.e., decreases in trait occurrences) and correlated to SSC frequencies, durations, and dosages. Ten traits were found to be useful in identifying sediment-metric thresholds for biological impairment. Although this dataset was not ideal in that sediment collections were not temporally coupled with fish collections, this study's objective was on evaluating whether a functional traits approach as suggested by Poff *et al.* (2006) had utility for potentially developing sediment TMDLs. Datasets with temporally coupled fish and sediment data are rare nationally, and may be non existent. Because of the limited availability of coupled datasets, the use of federal and state fish data and USGS flow and sediment data for ecoregion-scale analysis appeared appropriate, considering the analysis relied on fish presence and absence data sorted into functional-trait occurrence matrices. The potential sediment thresholds identified in this study at a minimum, provide useful information to support further study and refinement of the relations between sediment metrics and biological impairment within a functional traits framework. The same methodologies applied in this study could be used for long-term studies designed to collect sediment and fish data concurrently, along with more detailed physical-habitat data.

This approach provided a means to link sediment metrics to biological impairment, but does not identify potential causative agents that generate elevated suspended sediment levels leading to biological impairment. In order to get to causative relationships as needed for development of a TMDL corrective action plan, a second tier study would be needed to investigate watershed land-use characteristics and identify human activities that could increase suspended-sediment loads to streams (e.g., ranching, logging, mining, urban development). A second tier study could also investigate the potential indirect effects of habitat degradation on SSC relationships as found in this study. For example, reach-scale studies as described in Kauffman *et al.* (2008) provide a means to quantify mesohabitat and bed substrate quality. Even without further study, findings from this research suggest channel stability and it contribution to suspended sediment loads were potential causes for impairment. Therefore, land managers know that applying best management practices (BMP) to reduce elevated SSC will reduce impairment. BMP can

include bank protection measures, and channel gradient improvements to retain gravel substrate where ample material sources occurred historically and presently (FISRWG 1998).

This ecological analysis in this study concentrated on four major trait groups (mesohabitat preference, feeding location and trophic structure, and spawning behavior), which application is supported by fisheries studies in the western Great Plains region (Bramblett and Fausch 1991; Rahel and Hubert 1991; Welker and Scarnecchia 2004; Hoagstrom and Berry 2008; Fischer and Paukert 2008). Pool habitat use in streams and small rivers is dominant in this region apparently because of the harsh nature of flow environment (Lohr and Fausch 1997; Koel and Peterka 2003; Hoagstrom and Berry 2008). Although, complex pool habitats appear to provide resilience to hydrological impacts and regionally do not influence fish distribution (Fausch and Bramlett 1991). Schwartz and Herricks (2008) found in prairie streams, complex reach-scale platform morphology provide high-flow habitat patches leading to resilience of fish assemblages. Distinct differences in fish assemblages have been found between streams and rivers, where rivers were considered to be hydrologically stable leading to changes in fish species community composition but not richness (Hoagstrom et al. 2006; Fischer and Paukert 2008). It appears feeding location and trophic structure are a key trait groups, as others have found fish distribution strongly correlated to feeding habits (Bonner and Wilde 2002; Hoagstrom and Berry 2008). Welker and Scarnecchia (2003) found a distribution shift in castostomid fishes between disturbed and undisturbed river reaches. Hoagstrom and Berry (2008) found fish mouth and head morphology, related to feeding habit influence fish distribution. Spawning behavior was found correlated to hydrologically stability and substrate characteristics, where nest builders and brood hiders apparently benefit in variable flow environments of streams (Koel and Peterka 2003). In this ecoregion, expression of functional traits by fish communities appears to regulate fish distribution, and adequately filling niche dimensions for a guild analysis. Many of these trait relationships influence fish distribution at the local scale, but broad-scale environmental gradients also strongly organize fish assemblages and distribution.

In the western Great Plains, two environmental gradients strongly influence fish distribution and abundance; they are stream size (drainage area) and elevation (Rahel and Hubert 1991; Hoagstrom *et al.* 2006). Rahel and Hubert (1991) identified a shift from a salmonid assemblage to a cyprinid-castostomid assemblage below 2000 m, also recognizing a shift in decreasing pool habitat and increasing water turbidity. All the sites in this study were below 2000 m, therefore fish assemblages were mostly comprised of cyprinids and castostomids. Turbidity was also identified as a major environmental gradient in these streams and rivers, in addition to water conductivity (Koel and Peterta 2003; Fischer and Packert 2008). The turbidity gradient as observed by others is likely related to suspended sediment stressor and channel stability gradients.

Sediment yields were found to be significantly greater in unstable channels than stable channels for this ecoregion, and sediment frequency, duration, and dosage were also greater in unstable channels (Sections 5.3, 5.4 and 5.8). Therefore, it appears that a metric for channel stability could be appropriately applied as a surrogate for elevated

SSC levels. In this study, channel stability was found to be equivalent in strength as drainage area and elevation gradients, in organizing functional traits composition within the dataset. This is an important finding because it suggests that the suspended sediment stressor gradient can lead to altered fish assemblages, and linked to geomorphological stability. The main functional traits altered by channel stability in this study were preferred pool habitat in streams and shallow waters in rivers (HABPOOL, HABSW), and spawners that build nests and guard eggs (SPGNGR, SPGNE), which suggest an impairment co-relationship with suspended sediment transport and channel morphology (i.e., habitat quality). In this study, examination of potential sediment thresholds accounted for the influence of natural environmental gradients by correlating them with functional traits occurrences. When correlations were observed, it provided additional information to possibly explain co-relationships with the suspended sediment stressor gradient.

Because multiple thresholds were identified by this study's functional traits approach, professional judgment is still required to decide which thresholds to use for watershed TMDL management. The value of the functional traits approach is that agencies can define TMDLs based on a loss of ecological function related to specific functional traits, and natural environmental gradients related to watershed drainage area and elevation when relevant. This allows for watershed unit implementation of TMDLs. Alternatively, a broad regional implementation of the minimum thresholds could be applied for TMDLs, but this becomes a management decision. Overall, the functional traits approach was found to provide useful ecological information and potential suspended sediment thresholds for biological impairment that can support the TMDL process.

6. SUMMARY AND CONCLUSIONS

The main purpose of this study was to use scientifically-defensible methodologies by which to determine 'reference' or 'target' suspended-sediment transport rates for selected Level III Ecoregions in EPA Region 8. The geographic scope of this project covered the states of Idaho, Montana, North Dakota, South Dakota, and Wyoming. Six of the Level III Ecoregions located within EPA Region 8 were addressed in this report: #15, Northern Rockies, #17, Middle Rockies, #42, Northwest Glaciated Plains, 43#, Northwest Great Plains, #46, Northern Glaciated Plains, and #48 Lake Agassiz Plain. Sufficient data were available to also determine 'reference' values for some of the Level IV ecoregions within Ecoregion 43. 'Reference' values were obtained from analysis of the central part of the distribution of suspended-sediment loads for streams that were determined to be geomorphically stable at the time of suspended-sediment sampling. Sediment-load data were then divided by drainage area (in km^2) and expressed as sediment yields (load /km^2) so that streams of different drainage areas could be compared. These results were calculated for an important geomorphic discharge known as the 'effective discharge' and represented by the flow that occurs, on average, once every 1.5 years ($Q_{1.5}$). These are expressed in units of T/d/km^2. To avoid confusion and the tendency to want to multiply the $Q_{1.5}$ value by 365 to obtain an erroneous annual value, 'reference' sediment-transport rates were re-calculated using mean-daily flow data and expressed in units of T/y/km^2, providing mean annual suspended-sediment yields.

Statistical analysis of the differences between stable and unstable sites within each Level III Ecoregion were found to be significant at the 0.05 probability level with unstable sites generally transporting an order of magnitude more sediment per square kilometer than stable sites. These represent geomorphically, and perhaps ecologically important differences, and provide support for the overall approach used here to determine 'reference' rates for suspended-sediment transport. At the $Q_{1.5}$ discharge, 'reference' yields range over two orders of magnitude; from 0.0039 T/d/km^2 for Ecoregion 46, to 0.116 T/d/km^2 for Ecoregion 17. Mean-annual 'reference' suspended-sediment yield values varied by a single order of magnitude, from 0.351 T/y/km^2 to 4.73 T/y/km^2 also for Ecoregions 46 and 17, respectively. Concern over the use of these results for large drainage basins was investigated by sorting 'reference' data into order-of magnitude drainage-area size classes. There were sufficient data to make comparisons using results from Ecoregions 17, 43 and 46. Results seem to show no consistent trend between suspended-sediment yields and drainage basin size class in Ecoregions 17, 43 and 46. There are, however, trends within ecoregions. In contrast to the findings in Ecoregion 17 and 43, an increasing 'reference' mean-annual suspended-sediment yield with drainage basin area was not observed for Ecoregion 46. Most of the differences between drainage-area classes were either not significant, contained insufficient data, or, in the case of Ecoregion 43, showed a greater value for the largest size class. This latter finding is counter to the generally assumed reduction in yields for very large basins due to sediment storage.

Sufficient data were available to evaluate the significance of 'reference' transport rates in four Level IV Ecoregions within Ecoregion 43; Missouri Plateau (43a), River Breaks

(43c), Montana Central Grasslands (43n), and Powder River Basin (43w). Level IV Ecoregions 43n and 43w showed significant differences (at the 0.05 level) between stable and unstable sites for both mean-annual values as well as those at the $Q_{1.5}$. Mean-annual 'reference' values were significant for region 43c, 'reference' yields at the $Q_{1.5}$ were not significantly different from the unstable values

Additional analyses were performed on data from Ecoregion 43 at the basin scale. The Fort Randall Reservoir and Powder River drainage basins displayed the highest yields when considering all sites in Ecoregion 43; 147 T/y/km^2 and 60 T/y/km^2, respectively. Channels in these basins transport large amounts of sediment at both high and low discharges, making them major contributors to suspended-sediment load in Ecoregion 43. 'Reference' suspended-sediment transport rates could not be calculated individually for these drainage basins because the sediment-transport data were derived mainly from unstable channels. There are very few drainage basins in Ecoregion 43 where sufficient data exists for the separation of mean annual suspended-sediment yield data by relative channel stability. The only significant 'reference' yields by specific drainage basin were for the Tongue River Basin: mean annual (1.30 T/y/km^2) and for the $Q_{1.5}$ (0.0165 T/d/km^2).

To investigate the possibility of developing a median 'reference' sediment-transport relations (of the form Load = coeff. * Discharge ^{exp}) for each ecoregion, the initial, single-stage rating equations for each site were sorted again into stable and unstable groups. Within each ecoregion, results showed roughly order-of-magnitude differences between loads using ratings for stable and unstable sites at a given discharge. Differences between median stable and unstable ratings were found to be statistically significant only for Ecoregions 43 and 46. Differences for Ecoregions 17 and 48 were more subtle. The median 'reference' ratings can, however, be broken into two groups: 'Montane' ecoregions characterized by steeper ratings (higher exponents) and low coefficients, and the 'Plains' ecoregions, characterized by moderately-sloped ratings but higher coefficients. Differences in physiography, boundary characteristics and land use help explain these variations. Coefficients and exponents for these general 'reference' equations are provided.

All sediment-transport data were re-characterized in terms of the frequency and duration of suspended-sediment concentrations. Data expressed in these terms and sorted into stable and unstable groupings are potentially more useful to biologists and aquatic ecologists seeking functional links between sediment transport and biologic metrics. In addition, sediment 'dosage' was calculated as the product of concentration and duration for use in an ecological analysis and to investigate its use for linking suspended-sediment to biological impairment. These metrics were also differentiated by stability class. Median suspended-sediment concentrations were about an order of magnitude lower in stable or 'reference' channels at a given flow exceedance (or frequency) than in unstable channels over most of the range of flow frequencies. Differences in the frequency of occurrence of suspended-sediment concentrations are more important (significant) at moderate and high flows. The 'Montane' Ecoregions (15 and 17) stand out from the relations for the 'Plains' Ecoregions (42, 43, 46 and 48) with low, almost constant

concentrations for durations from about one month to one year for both stable and unstable streams. These diverge into the expected pattern of higher concentrations in unstable channels for the shorter duration, more extreme events. The durations of specific concentrations are almost always greater for the unstable channels in all of the ecoregions, lending further support to the idea of using these types of data to investigate differences in ecological condition.

Sediment-dosage data for all of the Ecoregions show distinct differences between stable and unstable sites across the range of concentrations. The same can be said for the inter-quartile ranges of these data, providing further support of their potential value. Across the range of concentrations, the highest suspended-sediment dosages occur at unstable sites in Ecoregion 43. In terms of dosage in stable, 'reference' streams, Ecoregion 43 generally displays the greatest values across the concentration range (about 200 to 1,000 mg-d/l) although Ecoregion 17 has similar dosage values at high concentrations and flows (low exceedance). As might be expected, Ecoregion 15 displays the lowest dosage values across the same range of concentration exceedances (10 to 200 mg-d/l) while the remaining 'Plains' Ecoregions have intermediate values (Ecoregion 42 and 43 show intermediate 'reference' dosage values (generally between 100 and 900 mg-d/l). 'Reference' sediment dosage attain peaks at 1% exceedance for the two montane ecoregions (15 and 17) indicating that dosages at these flows are potentially important for sediment-sensitive organisms. In contrast, in the 'Plains' Ecoregions where higher concentrations occur over a broader range of flows, it is the more moderate 30th to 70th exceedance concentration that appears to be the critical value.

The metric, 'dosage impact' represents the difference in sediment dosage for stable and unstable conditions at a given concentration exceedance. The greatest sediment-dosage impacts occur in Ecoregions 42 and 43 across the entire range of concentration exceedances. This suggests that biological impairment due to sediment dosage may occur not only at the high flow-concentration events, but may also be linked to the generally higher concentrations that persist over long periods of time at moderate flows. This is borne out by the ecological analysis in Ecoregion 43. This appears to be the case with all of the 'Plains' Ecoregions. Traces for both of the montane ecoregions show the biggest sediment-dosage impact at the 0.1% exceedance level, again indicating that high flow events are potentially the most critical to sediment-sensitive biota.

Analytic problems were encountered in certain geographic areas where only a few historical USGS data sets were available. This resulted in a lack of statistical significance when comparing sediment-yield data from stable and unstable sites, particularly when Level III ecoregion data were further sub-divided into Level IV or into individual basins. 'Reference' values based on small sample size may be of limited value, as described in each metric section. Solutions to the problem of an insufficient number of sites can only be realized by collecting more flow and suspended-sediment transport data, particularly at stable, 'reference' locations. This would certainly increase the reliability of the 'reference' metrics in areas where only a little data exists today. As the principal sediment data collection agency in the United States, the USGS has seen a reduction in funding for its gauging station network over the past decade. If there are concerns about

data gaps in sediment transport, additional funding for the USGS and other data collection agencies should be made available. In this regard, it is important to keep in mind that these types of data collection efforts must extend for years so that sediment samples are obtained over the range of the flow series. This may be only a few years for sediment, but needs to last for at least a decade for flow.

Frequency and duration of suspended-sediment concentrations, and dosage were used in the ecological analysis which attempted to relate sediment metrics to biological impairment. The ecological analysis consisted of a functional-traits approach using fish data from the Northwestern Great Plains (Ecoregion 43) because this ecoregion had greatest number of sediment-collection sites as well as the greatest potential of finding sites with co-located fish data. The final analysis included 58 sites with adequate suspended-sediment transport data and fish collections from federal and states agencies. Sediment metrics were computed for fish exposure months March through November, the period of time fish would be expressing their biological traits of habitat rearing preferences, feeding habits, and spawning behavior. For each site, occurrences of 20 different functional traits were compiled based on the presence of fish species that express that particular trait. A correlation analysis among suspended-sediment metrics and fish functional traits found three different types of impairment response; correlations across a broad range of concentration frequencies, and at both upper and lower ranges of concentration frequencies. Trait occurrences for fish that prefer pool habitat in streams were correlated across a broad range of frequency and duration of concentrations. In contrast, trait occurrences for fish that prefer shallow water habitat were correlated at the upper range of frequency and duration of concentrations; and piscivores were correlated with the lower range of frequency and duration of concentrations.

Overall, the functional traits approach appeared useful to identify potential suspended-sediment "thresholds" for biological impairment. Traits related to rearing habitat, feeding trophic structure, and spawning behavior were found to be impacted by elevated levels of suspended sediment. Of the twenty functional traits used in this study, ten correlated with a different suspended-sediment concentration frequency, duration and/or dosage. This result illustrates the complexity and futility in identifying a single biologically-based "threshold"; because different concentration levels appear to impact fish functional traits differentially. In addition, some traits were positively correlated with sediment metrics, inferring that elevated levels of suspended sediment may improve recruitment of some species. For example, non-guarding spawners that disperse their non-adhesive eggs into the water column, appear to benefit in this way because increased turbidity reduces the chances of egg being preyed upon.

A functional traits approach produces multiple sediment thresholds for impairment. Regional biologists with knowledge of fish distributions and traits of species to be protected can, therefore, use a specific threshold based on which ecological function(s) are to be protected. The ecological analysis found the sediment-dosage metric useful. Of the ten functional traits only one did not correlate with dosage metrics but rather with the sediment-duration metric only. Dosage relations and response to regional biota would

likely vary, but the ecological analysis was conducted for a single ecoregion with the goal of testing a protocol rather than defining absolute dosage thresholds.

Using ordination eigenanalysis, channel stability was found to be at least as importantr two natural environmental gradients, drainage area and elevation in explaining variance of functional trait occurrences among sites. This finding suggests channel stability, expressed in terms of elevated sediment concentrations, is an important environmental condition that affects fish distribution, but is co-dependent on watershed size and elevation. Since some habitat traits also correlated with drainage area, it may be that the channel stability classification and thresholds generated by this geomorphic analysis are ecologically more relevant in subwatersheds, and may not be as relevant in large rivers in Ecoregion 43.

Sufficient evidence was found in the ecological analysis to support the utility of RGA determinations of stable-unstable reaches, and subsequent sediment-transport differences. Whether the ecological consequences are direct or indirect, it appears fish species that build and guard nests occupied stable reaches more than unstable reaches. Likewise, fish species that spawn by egg dispersion were found more in unstable reaches than stables reaches. This finding suggests that sedimentation imposes an ecological stress on fish species that build nests for spawning. In general, ordinations with autecological attributes explained more than 50% of the variance for Axis 1 and 2, which is reasonable considering the number of environmental factors that affect fish distribution. Findings suggest that fish community structure is altered because watershed disturbances, observed by differences in stable and unstable reaches. Sedimentation may be directly impacting spawning success of nest builders, and indirectly modifying physical habitat to promote herbivores and piscivores. However, many fish species found in this ecoregion were tolerant species, found in both stable and unstable reaches.

6.1 Application of 'Reference' Sediment Metrics

Results of this study provide a scientifically-defensible methodology and series of 'reference' sediment metrics by which to develop targets for sediment TMDLs in the studied Ecoregions of EPA Region 8. These may take the form of suspended-sediment yields (load per unit area at the $Q_{1.5}$ or as annual values), frequency of occurrence of given concentrations, continuous duration of occurrence, or as a sediment 'dosage'. In most cases, the metrics are not single, absolute values but are provided as ranges, due to the inherent natural variability within groups (ie. Level III and IV Ecoregions). Different metrics may be appropriate in different settings according to the designated use, the statistical significance of the data and the type of data that is available for the TMDL location in question. These issues, including those of application, data significance and data uncertainty are described in detail in the sub-sections of the report that pertain to each of these metrics. A list of the different 'reference' sediment metrics that are available to TMDL practitioners is provided in Table 47. Also included in Table 47 are references as to where to find both the specific 'reference' values (ie. Tables 14 and 16) as well as the statistical tests of significance (ie. Tables 15 and 17).

Table 47 - List and location of 'reference' sediment metrics and associated statistical significance analyses determined in this study

"Reference" Sediment Metric	Section	"Reference" values Table number	"Reference" values Page number	Statistical Significance Table number	Statistical Significance Page number
Bed-material characteristics (Embeddedness)	5.2	12	51	-	-
$Q_{1.5}$ suspended-sediment yield (All Level III Ecoregions)	5.3	14	53	15	55
Mean annual suspended-sediment yield (All Level III Ecoregions)	5.4	16	57	17	59
$Q_{1.5}$ suspended-sediment yield for Ecoregion 43 Level IV Ecoregions	5.6.1	26	68	28	70
Mean, annual suspended-sediment yield for Ecoregion 43 Level IV Ecoregions	5.6.1	27	69	29	70
$Q_{1.5}$ suspended-sediment yield for Ecoregion 43 sub-basins	5.6.2	34	75	Insufficient data	-
Mean, annual suspended-sediment yield for Ecoregion 43 sub-basins	5.6.2	35	78	Insufficient data	-
Suspended-sediment transport rating equations	5.7	37	82	36 and 38	81 and 85
Suspended-sediment concentration for a given flow frequency	5.8.1	39	90	-	-
Suspended-sediment dosage	5.8.3	40	97	-	-

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